

Aeronautics and Space Report of the President

1986 Activities

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Aeronautics and Space Report of the President

1986 Activities



**National Aeronautics and Space Administration
Washington, D.C. 20546**

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The seven crew members of Space Shuttle Challenger Flight 51-L: (Back row, from left to right) Mission Specialist Ellison S. Onizuka, Teacher in Space Participant Christa McAuliffe, Payload Specialist Gregory B. Jarvis, and Mission Specialist Judith A. Resnik; (Front row, from left to right) Pilot Michael J. Smith, Commander Francis R. "Dick" Scobee, and Mission Specialist Ronald E. McNair.

Summary

During 1986, advances that were made in the areas of aeronautics, space science and applications, and space exploration, involving several federal agencies, demonstrated the Nation's abiding commitment to improve the quality of life on Earth and to extend human enterprise beyond Earth. However, the Space Shuttle Challenger accident, and the subsequent investigation and recovery operations, were the dominant events of the year, affecting a broad range of national and international space plans and policies.

The year's successful Space Shuttle mission began with the launch of flight 61-C on January 12, using the orbiter Columbia. The 6-day mission carried the Materials Science Laboratory; the first Hitchhiker payload-opportunity carrier; the Infrared Imaging Experiment; 13 Getaway Specials; and RCA's Satcom K-1 communications satellite was deployed. One of two payload specialists on the flight was U.S. Representative Bill Nelson who participated in a number of experiments for the National Aeronautics and Space Administration (NASA).

On January 28, Space Shuttle Challenger flight 51-L was launched at 11:38 a.m. Aboard were Francis R. "Dick" Scobee, commander; Michael J. Smith, pilot; Judith A. Resnik, Ellison S. Onizuka, and Ronald E. McNair, mission specialists; and payload specialists Gregory B. Jarvis, Hughes Aircraft Company, and Christa McAuliffe, the first teacher in space. Flight 51-L ended 73 seconds later in an explosive burn of hydrogen and oxygen propellants that destroyed the External Tank and exposed the spacecraft to severe aerodynamic loads that caused complete structural breakup. All seven crew members perished. Subsequently, President Reagan announced the formation of the Presidential Commission on the Space Shuttle Challenger Accident to determine the probable cause and necessary corrective actions. After conducting an extensive investigation, the Commission made important recommendations designed to insure the return to safe flight. NASA's plan to implement the recommendations of the Commission was submitted to President Reagan on July 14.

After extensive studies of the entire Shuttle Transportation System program were conducted, NASA announced February 1988 as

the target date for resuming Shuttle flights. Based upon a reduced flight rate, a 3-year projected manifest was issued that accommodated the payload backlog as much as possible. In addition, the President announced his support of the construction of a vehicle to replace Challenger, and of a new policy on the commercial use of space that emphasized private sector launches of commercial satellites, except for those that are uniquely suited to the Shuttle or have national security or foreign policy implications.

In 1986, expendable launch vehicles (ELV's) continued to provide launch support to satellite users. Five launches were conducted for the Department of Defense (DOD) and the National Oceanic and Atmospheric Administration (NOAA) using Scout, Delta, Atlas/Centaur, and Atlas E/F vehicles. In addition, NASA initiated studies on the need to establish a Mixed Fleet Transportation System that would consist of the Space Shuttle and existing or new ELV's.

In lieu of using the Centaur G prime upper stage to launch planetary payloads, the Inertial Upper Stage (a launch vehicle that fits into the Shuttle's cargo bay) was selected for the Magellan, Galileo, and Ulysses planetary missions.

In the area of space exploration, Voyager 2 became the first spacecraft to fly past Uranus, providing prime scientific data on that planetary body. In an unprecedented, coordinated effort, Halley's Comet was studied extensively by scientists and astronomers from around the world. Also, in the process of star formation, astronomers observed the stage where the collapsing object is closer to attaining stellar dimensions than anything previously observed; and the fastest known spinning binary pulsar was discovered.

The year 1986 marked the 25th anniversary of the use of Radioisotope Thermoelectric Generators (RTG's). Through the years, RTG's delivered by the Department of Energy to NASA and the DOD provided safe and highly reliable electric power sources that contributed to the success of some of the most ambitious and spectacular astronomical events ever undertaken by the United States. RTG's aboard spacecraft studying the interplanetary medium, Pioneer 10 and Pioneer 11, launched in 1972 and 1973, respectively, and the Voyager 1 and Voyager 2, launched in 1977, are still operational.

Under a White House directive, NASA and DOD continued to examine technologies that would improve launch capabilities in the post-1995 period. In addition, studies were initiated to examine options for new rocket engines, advanced propulsion recovery systems, and a second-generation Space Shuttle.

NASA and DOD also initiated the joint National Aero-Space Plane (NASP) research program that could lead to a whole new class of aerospace vehicles. The goal of the program is to develop hypersonic and transatmospheric technology for aerospace vehicles that are powered by airbreathing rather than rocket propulsion. NASP is a technology development program that will lead to a decision on building and flight testing the X-30 flight research aircraft. The X-30 would serve as a research vehicle to demonstrate the technologies developed to attain higher altitude and Mach numbers, and to validate the integration of the technologies into an aircraft. The performance goals planned for the vehicle include horizontal takeoff and landing from conventional runways, sustained hypersonic cruise in the atmosphere, and acceleration to orbit and return. Using the technology developed for the NASP, a family of future operational vehicles might include a next-generation space transportation system, high-altitude, high-speed military interceptor and reconnaissance aircraft, and hypersonic cruise transport.

Advances in other joint NASA/DOD research programs, such as the X-29 forward-swept wing experimental aircraft, the X-wing research aircraft, the tilt rotor/JVX aircraft, and the mission adaptive wing, increased the technology base substantially for civilian and military aviation.

In 1986, the Federal Communications Commission (FCC) authorized, conditionally, two companies to provide international telecommunications services through satellite systems separate from the International Telecommunications Satellite Organization (INTELSAT). Since the FCC issued its regulatory policies on independent satellite systems in 1985, a total of seven companies have been granted conditional authorization to establish these systems. In December 1986, INTELSAT's Board of Governors approved the U.S. proposal to establish separate systems. In related activity, the FCC allocated 27 MHz of spectrum for domestic mobile satellite services, and determined that joint owner-

ship of a mobile satellite system would be the best way to provide a variety of services to the public. In addition, advances in technology resulted in new applications of satellite-delivered communications. The FCC granted approval to a company to construct, launch, and operate three satellites that will provide radio determination satellite service and ancillary message service.

In accordance with provisions of the Land Remote Sensing Commercialization Act of 1984, the Earth Observation Satellite Company (EOSAT) has operated the land remote sensing satellite system (Landsat). The Company initiated development of a satellite receiving center, and an operations and control center that will be used for capturing and processing data and flight control for the next-generation Landsat 6 and future spacecraft. The Earth Resources Observation System (EROS) Data Center of the U.S. Geological Survey (USGS) supported the transition of Landsat operations, and data marketing and sales from NOAA to EOSAT. In 1986, approximately 26,000 film and digital Landsat products were generated and distributed to users worldwide.

To encourage U.S. private sector involvement and investment in commercial space ventures, NASA's Office of Commercial Programs established and funded four additional Centers for the Commercial Development of Space, for a current total of nine. As an alliance of industry, academia, and government, the Centers will use the space environment to stimulate high technology research that may lead to the development of new products and services with commercial potential. The revised U.S. space launch strategy gives the commercial expendable launch vehicle industry a primary role in meeting public and private requirements for launch services. In response to policy changes, the Office of Commercial Space Transportation, Department of Transportation, developed regulatory guidance and interagency relationships designed to create a more favorable environment for the industry. In another development, the Department of Transportation's Federal Aviation Administration entered into an agreement with NASA to develop system requirements for forward-looking aircraft wind shear sensors, such as Doppler radar and Doppler lidar, that will sense wind shear and allow aircraft to be alerted to hazardous areas.

In the international arena, U.S. representatives continued to meet with European, Japanese, and Canadian representatives to negotiate agreements on the detailed design, development, operation, and utilization of the Space Station. Agreements from the negotiations are expected to commit all international partners to hardware investments, operational roles, and use of the Space Station for many years to come.

As the agency responsible for representing U.S. foreign policy interests, the Department of State was actively involved in discussions with nations whose plans for space were adversely affected by the Space Shuttle Challenger accident, and by changes in U.S. commercial space policy.

A number of federal agencies participated in preparations for the International Telecommunication Union's World Administrative Radio Conference for Mobile Services (Mobile WARC) that will be conducted in Geneva, Switzerland in 1987. In July, a draft of the U.S. technical proposals on mobile services from terrestrial and satellite communications, radio determination and radio navigation satellite systems was presented to 41 countries. In addition, U.S. representatives were involved in plans for the second session of the International Telecommunication Union's World Administrative Radio Conference on the Use of the Geostationary Satellite Orbit and the Planning of the Space Services Utilizing It (Space WARC), commonly known as ORB (2) WARC, scheduled for 1988. The objective of the conference is to guarantee to all nations equitable access to the geostationary satellite orbit and to the frequency bands allocated to space services.

The Arms Control and Disarmament Agency continued to articulate the U.S. position on space arms control in the Defense and Space Negotiating Group, part of the Nuclear and Space Talks, a bilateral U.S.—Soviet arms control negotiation that began in March 1985.

The United States Information Agency's popular satellite telecast service, Worldnet, broadcast several programs about U.S. activities in space, such as Voyager 2's encounter with Uranus, the future Space Station, the Young Astronauts Program, and the Challenger accident. In addition, most of the Voice of America's 41 foreign language services covered a variety of stories about the U.S. space program.

The National Commission on Space presented its proposed program and goals for the U.S. civil space program for the next 50 years.

The remainder of this chapter is a summary by function of U.S. aeronautics and space activities in calendar year 1986. The succeeding chapters present activities of individual agencies in greater detail.

Space Science

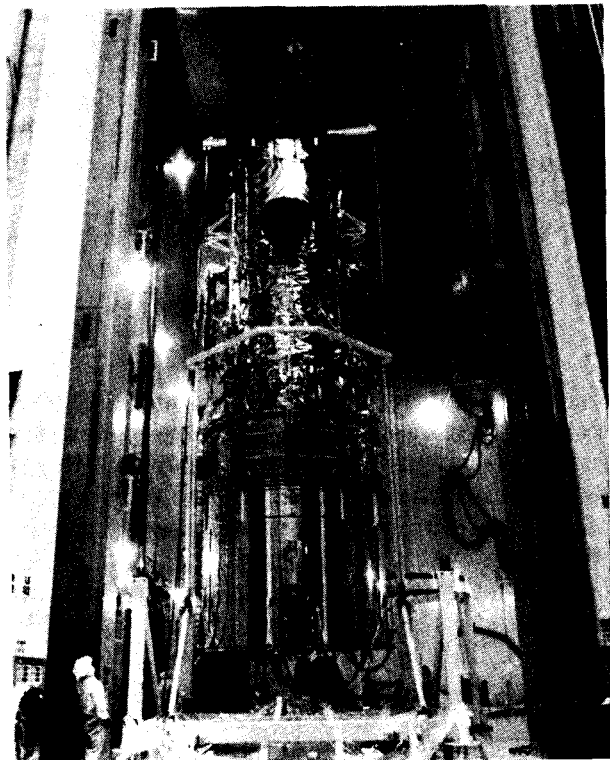
Space science programs include observations and studies of the universe and of the fundamental physical laws important to understanding the distant universe, exploration of the near universe, and efforts to acquire more knowledge about Earth's planetary features and environment. Investigations are conducted using satellites, space probes, the Space Shuttle, suborbital vehicles, and ground-based facilities. In 1986, the temporary loss of U.S. space launch capability precluded what was planned as "A Year for Space Science." However, scientists and astronomers maintained full schedules working on activities that did not require launches.

Study of the Universe

Astrophysics programs study the physical nature of the universe, from the Sun to the most distant quasars, to determine the laws that govern cosmic phenomena, and to learn the origins of the universe and how it will end. Many observations cannot be made through the Earth's atmosphere, so instruments to conduct studies must be carried above the atmosphere into space. Planning and development continued on the four Great Observatories; after they are launched into space, they will be able to observe objects at any wavelength in the electromagnetic spectrum.

Hubble Space Telescope (HST). Originally scheduled for launch in October 1986, the current flight manifest calls for launch of the HST late in 1988 or early 1989. The first of the four Great Observatories, it will carry five scientific instruments to study the stars, planets, and interstellar space, allowing scientists and astronomers to see clearly 10 to

30 times beyond what can be observed with existing instruments.



When placed in orbit, the Hubble Space Telescope will observe objects in the universe in visible and ultraviolet light with 10 to 30 times the clarity of existing ground-based observatories.

Gamma Ray Observatory (GRO). Final stages of manufacturing and assembling the four scientific instruments of GRO, the second of the four Great Observatories, continued. When it is placed in orbit in 1990, GRO will view objects clearly that are at least 10 times fainter than existing capabilities can observe, and will improve existing knowledge of the origin and location of gamma rays in the universe by a factor of 50 to 100.

Proposed Advanced X-ray Astrophysics Facility (AXAF). Proposed as the third of the four Great Observatories, AXAF would be 100 times more powerful for detecting x-rays from celestial sources than the highly successful High Energy Astronomy Observatory (HEAO-2) mission. Studies using AXAF would have a direct bearing on such important scientific fields as plasma physics, atomic and nuclear physics, elementary particle physics, and cosmology.

Proposed Space Infrared Telescope Facility (SIRTF). If placed in orbit, this proposed Facility, the last of the four Great Observatories, will span the infrared part of the spectrum with a thousand-fold increase in

sensitivity. It will be able to search for planets around the nearest stars; and spectra for planets that might be detected could reveal the chemical composition of their atmospheres and help to determine whether they might sustain life similar to that found on Earth.

High Energy Astronomy Observatories (HEAO's). Data obtained from the three High Energy Astronomy Observatories contributed significantly to existing knowledge about high energy astrophysical processes. Continued analysis of data from the HEAO-1 and HEAO-2 satellites revealed the presence of dense, x-ray emitting gas in the central regions of some galaxies, indicating a significant annual influx of matter; this discovery led to the unexpected observation of the formation of a galaxy. Analysis of data from the HEAO-3 satellite disclosed that gamma rays come from the plane of the Milky Way Galaxy.

Solar Maximum Mission (SMM). In orbit since 1980, the SMM's major achievement in 1986 was its observation of Halley's Comet when the Comet was too close to the Sun to be studied from the ground and by other spacecraft. Also, the SMM continued to obtain an unparalleled series of observations of the Sun's corona and sunspot activity.

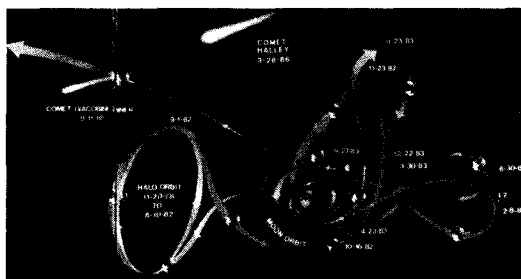
Spartan. Carrying instruments to observe Halley's Comet, the second Spartan and mission support systems, designed to release and recapture Spartan subsatellites, were destroyed during the Challenger accident. A new spacecraft and supporting systems are being built, and should be ready for a flight on the Space Shuttle in 1988.

Astro-1. Scheduled for launch in 1986, the Astro-1 payload, a Shuttle-borne observatory that will measure ultraviolet radiation from celestial objects, is now manifested for a flight in January 1991.

Solar System Exploration

Cometary Studies. In 1985 and 1986, the appearance of Halley's Comet was the focus of unprecedented international scientific study. Although NASA did not send a probe directly to intercept the Comet, it was studied extensively by U.S. scientists on the ground, and by aircraft, rockets, and existing spacecraft that included the Pioneer Venus Orbiter, the Dynamics Explorer, the Solar Maximum Mission, the International Ultra-

violet Explorer, and the International Cometary Explorer. In addition, NASA's Deep Space Network provided tracking and communications support to international spacecraft observing the Comet.



Flight path of the International Cometary Explorer. In March 1986, the spacecraft observed Halley's Comet from a distance of 35 million kilometers.

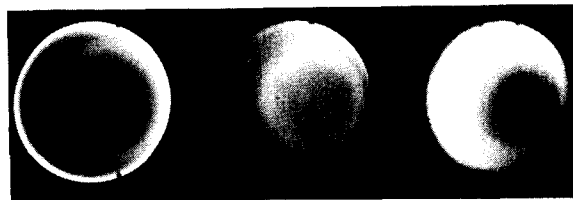
Voyager at Uranus. In January 1986, Voyager 2 became the first spacecraft to fly past Uranus, transmitting over 7,000 images of the planet that revealed two new rings, ten new moons, and an abundance of helium in its atmosphere comparable to that found on Jupiter and Saturn.

Pioneer Venus Orbiter. At a time when Halley's Comet was relatively close to Venus, the Pioneer Venus Orbiter obtained unique images of the Comet, and data on the chemical composition of its atmosphere. Also, instruments on the spacecraft made important new measurements of the solar wind interaction with Venus.

Pioneers 10 and 11. Pioneers 10 and 11 continued to measure the properties of the interplanetary medium in the outer solar system. The main scientific goal of both spacecraft is to search for the heliopause, the interaction boundary between the solar wind and interstellar space. During Voyager 2's encounter with Uranus, Pioneer 11's instruments monitored solar wind conditions.

Galileo and Ulysses. The separate Galileo and Ulysses missions to Jupiter were scheduled for launch in 1986. The Galileo mission, a joint project with the Federal Republic of Germany, will conduct an in-depth study of Jupiter's atmosphere, magnetic field, and moons; and could be launched from the Space Shuttle in 1989 or 1991, or by an expendable launch vehicle. The Ulysses mission, a joint effort with the European Space Agency, will provide the first view of the Sun and the solar system from above the ecliptic plane. Data obtained is expected to improve understanding of the Sun, and the effects of solar activity on the Earth's weather and climate. The

Ulysses mission is being considered for launch in 1989 or 1990.



Images of Uranus taken by Voyager 2 from a distance of 1.3 million miles

Mars Observer. Scheduled for launch in 1990, the Mars Observer will obtain images of the surface and atmosphere of Mars during the four seasons of one Mars year. In 1986, spacecraft manufacturers and geoscience and climatology experiments were selected for the mission.

Explorers. For the past nine years, the International Ultraviolet Explorer has provided ultraviolet spectra for studying comets, the outer planets and their satellites, the atmospheres of stars, the interstellar medium, and extragalactic objects. In 1986, it provided images of Halley's Comet during encounters by spacecraft from Japan, ESA, and the Soviet Union. From polar orbit, the Cosmic Background Explorer will map the sky and measure cosmic background radiation that is the focus of debate on the Big Bang theory of the exploding universe. In 1986, integration of the spacecraft began, and its instruments were tested at liquid helium temperatures. Also, plans continued on developing the Explorer Platform, a reusable spacecraft bus for Explorer payloads.

Life Sciences

The two major goals of NASA's Life Sciences program are to promote health and productivity in manned space flight, and to study biological processes and life in the universe.

Space Medicine. The crew of Shuttle flight 61-C investigated human responses to the low-gravity environment of space, such as motion sickness, and changes in body fluids, and were involved in echocardiography, hand-eye coordination, and treadmill stress tests. A Health Maintenance Facility is being developed for the Space Station that will allow space crews to exercise and have their health monitored.

Gravitational Biology. The goal of the Gravitational Biology program is to understand how gravity affects life on Earth and the weightlessness of space is used as a tool to understand life and its processes. Analysis of data on young, developing animals experiencing weightlessness on the 1985 flight of Spacelab 3 indicates a reduction in bone strength, suggesting that gravity loading is essential for normal bone growth. In addition, significant changes in muscle mass were observed.

Exobiology. The Exobiology program endeavors to understand the origin, evolution, and distribution of life in the universe. Recently, precursors of biologically important organic molecules were discovered in the interstellar medium. Studies indicate a direct link between these organic molecules and those found in primitive solar system bodies, fueling speculation that life exists elsewhere in the universe.

Controlled Ecological Life Support System (CELSS). The goal of the CELSS program is to develop a spacecraft system that continually recycles the solid, liquid, and gaseous materials required to sustain human life. Under the CELSS Breadboard Project for bioregenerative life support, a chamber was built that is designed to test techniques for growing plants in a closed environment.

Spacelab Flight Program

Following the Challenger accident, there was a reassessment of the Spacelab Flight program to try to accommodate the payloads that were previously scheduled for flights on the Shuttle. Payloads that are planned for early Spacelab flights include the Materials Science Laboratory, International Microgravity Laboratory, Space Life Sciences, and Atmospheric Laboratory for Applications and Science. Negotiations on a reimbursable Spacelab flight with Japan (Spacelab-J) continued.

Microgravity Science

The Microgravity Science and Applications program conducts research into the effects of reduced gravity on basic physical phenomena and processes. Research is focused on the areas of combustion, metals and alloys, electronic materials, glasses and ceramics,

biotechnology, and fluid dynamics and transport phenomena. Although 70 high-quality, ground-based investigations have been funded, new research efforts will require expanded program resources.

Communications

The United States has implemented a multifaceted communications satellite program that will allow it to meet foreign competition and maintain its preeminent status in the global marketplace.

Advanced Communications Technology Satellite (ACTS). ACTS technology will contribute to future domestic and global satellite networks. In 1986, laser technology and a steerable antenna were added to the items currently planned for ACTS. The antenna will extend ACTS coverage to states and areas outside the contiguous 48 states, such as Alaska, Hawaii, and South America. The spacecraft is scheduled for a Shuttle launch in late 1990.

Mobile Satellite. Within the next four to six years, the joint industry/government mobile satellite program will provide two-way satellite-assisted communication with cars, trucks, trains, boats, and aircraft. The FCC has allocated L-band frequencies for the domestic mobile satellite system, and is in the process of formulating service guidelines. The system is expected to create new U.S. hardware markets, business, and service industries.

Search and Rescue. The COSPAS/SARSAT system, which locates aircraft and vessels in distress, completed its first year of regular operation. Since its inception, it is credited with saving more than 675 lives, and is gaining worldwide acceptance. Research continues on techniques to reduce false alarm rates, and improve detection.

Advanced Technology Satellite (ATS-3). The ATS-3 continued to support the activities of several federal agencies, domestic and international relief organizations. In addition, satellite voice and data links in science and communication application experiments provided support to areas of North and South America, most of the Atlantic Ocean, and a large part of the eastern Pacific, including Hawaii and Antarctica.

INTELSAT and INMARSAT. At the end of 1986, INTELSAT maintained 15 satellites in

orbit: 1 IV, 1 IVA, and 6 V's in the Atlantic Ocean Region; 3 V's in the Indian Ocean Region; and 2 IVA's, and 2 V's in the Pacific Ocean Region. Three of the IVA satellites exceeded estimated maneuver life. Approval was granted for construction and application of 30 new Earth station facilities to access the INTELSAT system in the Atlantic and Pacific Ocean Regions for INTELSAT (digital) business, and television transmission and reception service.

In its fifth year of maritime satellite communications service, the 48-member International Maritime Satellite Organization (INMARSAT) leases three operational and three in-orbit satellites for the Atlantic, Pacific, and Indian Ocean Regions, and serves over 5,000 vessels. Seventeen coast stations are operating in 12 countries, and five more are expected in 1987. Second-generation satellites, the first of which is expected to become operational in 1989, will have 3 times the capacity of the current leased satellites.

The International Maritime Organization (IMO) is developing a global maritime distress and safety system that will use ship Earth stations through INMARSAT, and satellite emergency position-indicating radio beacons (EPIRB's) operating through COSPAS/SARSAT.

Domestic Communications Satellites. Currently, there are 27 domestic satellites operating in the geostationary orbit located between 69° and 143° west longitude. During 1986, no new domestic communications satellites were authorized for construction and launch. The FCC's Advisory Committee on 2° Spacing issued several recommendations relating to the areas of Earth stations, space stations, and coordination.

Direct Broadcast Satellites (DBS). Three "first-round" companies, previously granted permits to construct Direct Broadcast Satellites (DBS), were in the process of constructing DBS systems that are expected to be operational by late 1988. These companies will use 200 to 230-watt traveling wave tube amplifiers (TWTA's), together with various half-CONUS or full-CONUS beam configurations, to provide service throughout the United States. One of the "second-round" DBS companies has been awarded channels, orbital position, and launch authorization, and operations are expected by mid-1989. This system will use two 16-channel satellites equipped with 100-watt TWTA's to provide DBS service. In 1986, three companies

were granted conditional construction permits for new satellite systems, and three other DBS system applications that were filed are pending.

Military Communications Satellites. Military Satellite Communications (MILSATCOM) provide a variety of services worldwide in several frequency bands. In the Ultra High Frequency band, the Fleet Satellite Communications (FLTSATCOM) System, assisted by leased satellites (LEASAT's), provide low-capacity, command and control services to users of small, mobile terminals. The Air Force Satellite Communications (AFSATCOM) System provides global communications between the National Command Authorities and U.S. nuclear forces. In the Super High Frequency band, the Defense Satellite Communications System provides high-capacity command and control, intelligence, and multichannel communications service to a multitude of strategic, tactical and non-DOD users. The future Milstar Satellite Communications System will use the Extremely High Frequency band to provide jam-resistant, secure communications for the President, Joint Chiefs-of-Staff, and the Commanders-in-Chief. When completed, Milstar will provide the Nation's most survivable wartime communications capability. In 1986, full-scale development of the space and mission control segments of Milstar continued, and critical design reviews were scheduled for mid-1987 and early 1988.

Navigation Satellites. Navstar II, the last developmental Global Positioning System (GPS) satellite, was launched in 1985. In 1986, two of the seven developmental GPS satellites demonstrated the effects of age and performed marginally. GPS satellites provide radio position and navigation information to support defense missions worldwide.

Earth's Atmosphere, Environment, and Resources

In 1986, observations and knowledge of Earth, its atmosphere, environment, and resources, were advanced substantially by special space systems, programs, and experiments.

Monitoring and Analysis

Satellite Operations. The environmental satellites operated by NOAA for the Department of Commerce include both polar-

orbiting and geostationary spacecraft. NOAA satellites are used primarily to forecast weather and issue storm or natural disaster warnings. NOAA 6 and NOAA 9 provided the agency's polar-orbiting service for most of the year. These spacecraft view the Earth in the visible and infrared portions of the electromagnetic spectrum, using the Advanced Very High Resolution Radiometer, and move in Sun-synchronous orbits observing every part of the Earth at least twice daily, once in daylight, and once at night. NOAA 9 has been operational since December 1984; and NOAA 6 was able to fulfill most mission requirements until it was replaced by NOAA 10 in November 1986. NOAA H is expected to replace NOAA 9 in December 1987. Scientific instruments aboard the NOAA 9 and NOAA 10 spacecraft, which are associated with the Earth Radiation Budget Experiment, studied the physical processes that influence climate. Data obtained from these instruments, and those aboard the Earth Radiation Budget Satellite, are expected to help determine the role of clouds in the Earth's radiation budget.

GOES 6, the only fully operational geostationary satellite, continued to provide imaging and sounding data throughout the year. Because its rate of movement around the Earth equals that of the Earth's rotation, its observing position over the Equator remains fixed, allowing an uninterrupted view of the Earth. Included among the instruments it carries is the Visible and Infrared Spin-Scan Radiometer Atmospheric Sounder that provides day and night coverage of the Earth and its atmosphere. In 1986, an effort to launch a second geostationary satellite, GOES G, failed. Launch of GOES H, last in the current series of GOES spacecraft, is scheduled for February 1987. Design and development of the next-generation geostationary spacecraft, GOES I-M, began; and launch of the first satellite in this series is expected in 1989.

Atmospheric, Oceanic, and Geologic Research. In 1986, a three volume document entitled "Atmospheric Ozone 1985: Assessment of Our Understanding of the Processes Controlling its Present Distribution and Change," was published by the World Meteorological Organization. Approximately 150 scientists from 11 nations contributed to the assessment, and publication of the report was coordinated by NASA, FAA, NOAA, the United Nations Environment Program, World Meteorological Organization, Commis-

sion of the European Communities, and the Federal Republic of Germany. A major conclusion of the report was that increased concentrations of trace substances such as chlorofluorocarbons, methane, and carbon dioxide can perturb ozone distribution in the atmosphere and harm the global climate system and temperature structure. In related activity, federal and private organizations sponsored a scientific expedition to Antarctica to study the "ozone hole" that has been discovered there by ground and space-based instrumentation. Results of the study are expected to determine the cause of this phenomena, and to ascertain whether the Antarctic hole serves as a harbinger of atmospheric changes elsewhere on the globe.

In its third year of operation, the International Satellite Cloud Climatology Project (ISCCP) continued to collect data on the global distribution of clouds that was obtained from an international array of polar-orbiting and geostationary satellites. Also, the first field experiment was conducted by the university-government science team of the First ISCCP Regional Experiment (FIRE), a multiagency program studying the effects of cloud systems on climate.

Advanced remote sensing techniques are being developed for satellite observation of the Earth's atmosphere. A preliminary design study for placing a coherent Laser Interferometric Detection and Ranging Radar (LIDAR) wind sensor on the Space Shuttle was completed. This study provides a positive indication of the maturity of the technology, and allows serious consideration of the use of LIDAR's in satellite global wind sensors. Recently completed studies indicate that satellite observations of global wind profiles will dramatically improve understanding of large-scale atmospheric processes.

To achieve a better understanding of microbursts, severe thunderstorms and their associated downbursts, the Cooperative Huntsville Mesoscale Experiment (COHMEX) was conducted. It was supported by GOES and NOAA environmental satellites, Doppler radars, NOAA special rawinsonde coverage, the FAA, aircraft flights sponsored by the National Science Foundation, and special Tennessee Valley Authority rain gauge and surface reports. During the experiment, records were made of the most extensive weather system measurements ever taken by high-altitude aircraft.

The FAA determined that false alarms

from the six-sensor Low Level Wind Shear Alert System (LLWAS) were often caused by the location of the System. As a result, the FAA formed a team to assess the siting of all LLWAS's at 110 airports in the United States. To help reduce the rate of false alarms, new algorithms were developed for incorporation into the Systems as they are relocated during 1987 and 1988.

In oceanography programs, activities focused on the Tropical Ocean Global Atmosphere and World Ocean Circulation Experiments, and on the Global Ocean Flux Study. A number of spaceflight missions to study atmospheric and oceanic processes are planned for launch in the early 1990's. The first of two missions in the Physical Oceanographic program, NASA's Scatterometer will fly aboard the Navy's Remote Ocean Sensing System satellite. The second mission, the Ocean Topography Experiment (TOPEX), will be jointly conducted with the French Space Agency's POSEIDON project. The TOPEX satellite, with POSEIDON sensors aboard, will be launched by a European Ariane rocket in late 1991. Launched in 1978, the Nimbus-7 weather satellite has performed well beyond its expected one-year life span. Processing the satellite's Coastal Zone Color Scanner imagery into ocean-basin maps of chlorophyll was initiated, and the first map of this type that covered the North Atlantic was produced. In related activity, NOAA's National Ocean Service developed a Pacific Ocean Route Chart, for use by FAA's air traffic controllers, and a Navigational Aid Digital Data File that contains the geographic position, type, and unique characteristics of every navigational aid in the United States, Puerto Rico, and the Virgin Islands.

The USGS and NOAA signed an agreement to establish the Cooperative Federal Land Remote Sensing Research program. The goal is to promote greater operational and research use of remotely sensed data and related technology within federal and state governments, academia, and the private sector. NOAA trained several foreign scientists in applications of remote sensing data that included estimating precipitation from satellite imagery, assessing climate, and forecasting weather and crop productivity. The USGS conducted a workshop for scientists from six nations that covered the use of Landsat data for geologic, hydrologic, and vegetation analysis. The Department of Agriculture's Agricultural Research Service participated in an

experiment with the USGS and the University of Arizona on the use of remotely sensed spectral data for large-scale farm management.

Geodynamics research improves understanding of the evolution of the Earth, the interaction between the solid Earth, the oceans and atmosphere, and the nature and causes of earthquakes. More than 30 nations participate in U.S. geodynamics research, and there is intergovernmental cooperation between NASA, USGS, NSF, NOAA, and DOD. Joint projects and programs included measuring tectonic plate motion and the Earth's rotation, using fixed and mobile laser ranging systems, and a study of earthquake hazards in the Caribbean Basin. Through digital analysis of images recorded in the visible and near-infrared portions of the electromagnetic spectrum, USGS scientists made significant advances in identifying minerals in rock and soil, and in compiling maps showing their distribution.

Space Transportation

Most of the activity involving NASA's Space Flight program focused on the investigation of the Space Shuttle Challenger accident, examination of the entire Space Transportation System (STS) program, and a return to flight status. One communications satellite was boosted into orbit from the Space Shuttle Columbia; and five expendable launch vehicles were used to place military and civilian satellites into space. For the second time, a public official was flown aboard the Space Shuttle, and the first Hispanic-American journeyed into space.



On January 12, 1986, in the first Space Shuttle launch of the year, Space Shuttle Columbia rises into the early morning sky from Kennedy Space Center.

Orbiter

A total Systems Design Review of the orbiter was conducted, and a number of design modifications to enhance safety were identified. In addition, crew escape studies, hazard analyses, and critical items list reviews were conducted to improve safety margins on future flights. For the near-term, approval was granted to provide a crew bailout system through the side hatch of the orbiter. Also, the decision was made to procure a replacement orbiter, which is expected to be delivered in 1991.

A program was initiated to address key problem areas of the Space Shuttle Main Engine that were identified following Challenger's accident. Coincidentally, other problems were found, such as new critical turbine blade cracks and marginal turbopump bearing temperature.



As one of two payload specialists aboard Space Shuttle Columbia, Representative Bill Nelson participates in an experiment for NASA's Space Biomedical Research Institute.

Seven external tanks were manufactured and delivered. However, Challenger's accident resulted in significantly reduced production requirements.

The production of solid rocket boosters and motors was suspended, and activity focused on the failure investigation and on recovery actions for redesigning and recertifying the boosters.

Payloads. The design for operating the Spacelab Igloo Pallet configuration's mixed cargo mode, to support the Astro 1 mission, was completed and reviewed. In this configuration, using an igloo, two pallets, and the Instrument Pointing System, the Spacelab is scheduled to fly in January 1989. The Payload Operations Control Center at Marshall Space Flight Center was completed, and preparations are underway for it to support

the Astro 1 mission. Development of the configuration for the Spacelab Enhanced Pallet continued; it will be used for missions of the Space Technology Experiment Platform and Tethered Satellite System.

Shuttle Flight Operations

To improve operations facilities at the Johnson Space Center, old data processors in the Mission Control Center were replaced with four IBM 3083 computers; and plans to upgrade the Shuttle Mission Simulator were revised and accelerated.

Tethered Satellite System

The Tethered Satellite System, a cooperative development between NASA and Italy, will be capable of deploying and retrieving a tethered satellite up to 100 kilometers above or below the orbiting Space Shuttle. Critical Design and Manufacturing Reviews were conducted on the satellite; and science investigations were initiated for the first mission, scheduled for October 1990.

Advanced Planning

A prime contractor was selected to build the Orbital Maneuvering Vehicle, which will perform payload delivery to and retrieval from the Shuttle orbiter. Initial studies also were completed on a space-based Orbital Transfer Vehicle, featuring an aerobrake that significantly reduces propellant requirements. In addition, research was initiated in areas of key technology that could lead to options for new rocket engines, advanced recovery systems, and a second-generation Space Shuttle.

Commercial Use of Space

The Office of Commercial Space Transportation of the Department of Transportation was established to encourage, regulate, and promote a commercial expendable launch vehicle industry. One of the major consequences of the Challenger accident was the President's decision, announced in August 1986, to preclude use of the Space Shuttle for boost-

ing routine foreign and commercial satellites into space. The decision was later incorporated into the U.S. Space Launch Strategy, which requires a space transportation system composed of both expendable launch vehicles and the Space Shuttle. The revised space launch strategy emphasized that the Space Shuttle fleet would be used for missions requiring its unique capabilities, and that the commercial expendable launch vehicle industry would be a critical element in meeting Government and industry requirements for space.

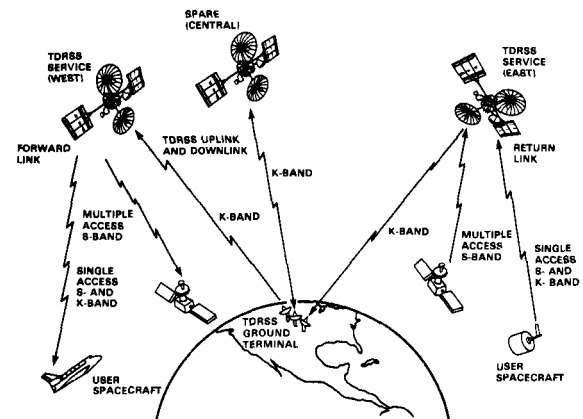
NASA's Office of Commercial Programs was established to encourage U.S. private sector involvement and investment in commercial space ventures, and to facilitate commercial application and transfer of existing aeronautics and space technology to the private sector. In 1986, four additional Centers for the Commercial Development of Space were established, for a current total of nine. The Centers will use the space environment to stimulate high technology research that may lead to the development of new products and services with commercial potential. More than 30 agreements have been executed with U.S. firms interested in conducting space-related research and development in the areas of pharmaceuticals, semiconductor electronic materials, metals and alloys, and organic polymers. The successful privatization of *NASA Tech Briefs*, the agency's primary publication on technology transfer, has enhanced NASA's interaction with industry. At the end of 1986, the number of industrial and business subscribers exceeded 130,000, which reflects a 70 percent increase in subscriptions from the previous two years.

Space Tracking and Data Systems

The Space Tracking and Data Systems program is responsible for planning, implementing, and operating worldwide tracking, data handling, and communications facilities and services that support flight programs of NASA and other agencies. Two Tracking and Data Relay Satellites (TDRS) that were scheduled for separate launches in 1986 would have completed the operational satellite constellation of three in orbit. The TDRS aboard Space Shuttle Challenger's flight 51-L was lost. However, two TDRS spacecraft are scheduled for launch when Shuttle operations resume in 1988.

The Deep Space Network (DSN) continued to support missions to explore the solar system, and was key to the success of Voyager 2's January 1986 encounter with the planet Uranus. During the international observations of Halley's Comet, the DSN supported Japan's effort to track its two spacecraft; provided backup tracking of the European Space Agency's Giotto spacecraft; tracked the Soviet Vega spacecraft as they approached the Comet; and supported other spacecraft, such as the Pioneer Venus Orbiter and the International Cometary Explorer, as they observed the Comet. In addition, efforts were underway to increase the sensitivity of the DSN in preparation for Voyager 2's encounter with the planet Neptune in 1989.

Major projects that became operational in the Communications and Data Systems program included a Time Division Multiple Access system, providing operational circuits, via satellite, that will improve communications throughout NASA's facilities; and a Program Support Communications Network, providing voice and data services to support the agency's institutional and programmatic requirements.



The future configuration for the Tracking and Data Relay Satellite System (TDRSS).

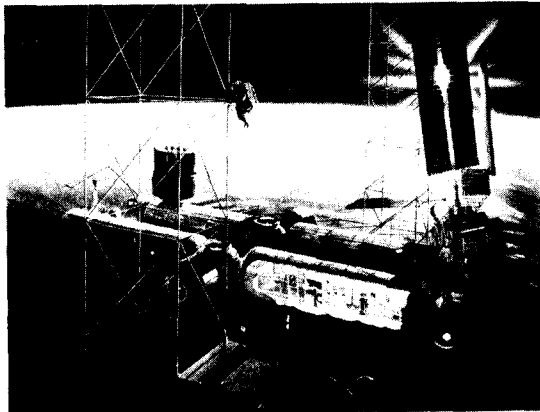
Space Station

In 1986, efforts to build the Space Station continued as NASA complied with the President's 1984 directive to establish a permanently manned presence in space by the mid-1990's.

The Space Station will be an orbiting scientific laboratory, and a permanent observatory in space. The facility will be used to process

materials and manufacture commercial products; assemble large spacecraft; stage deep-space missions; and service and deploy satellites, upper stage rockets, and scientific instruments.

During 1986, the most significant achievement in the Space Station program was the selection of the dual keel baseline configuration that will be used to guide detailed design and development activities. Most of the work on the 3-year definition and preliminary design phase of the program was completed. Changes were made in the Space Station's assembly sequence; technical and management problems were identified and resolved; and progress on agreements for hardware development was made with NASA's international partners: the European Space Agency, Canada, and Japan. By the end of the year, NASA was preparing to release to industry a Request for Proposals to design and build the Space Station.



Artist's conception of the four pressurized modules that are part of the baseline configuration of the permanently manned Space Station.

Aeronautics and Space Research and Technology

The United States has long been recognized as the world leader in aeronautics research and technology. However, U.S. leadership in these areas is being challenged by foreign industrial competitors and potential military adversaries. For the United States to preserve its leadership status in civil and military aviation, the Nation must pursue those opportunities in aeronautics research and technology that will enable important advances in aircraft performance and capability.

In order to meet the goals for the Nation's activity in aeronautics research and technology that were established by the White House Office of Science and Technology Policy, NASA redirected its Aeronautics Research and Technology program toward emerging technologies that have potential for order-of-magnitude advances in aircraft performance and capability. These technologies span the flight spectrum from advanced rotorcraft to hypersonic vehicles for both civil and military uses. Wind tunnels, simulators, supercomputers, and experimental flight vehicles are some of the research tools used to design and develop future generations of civil and military aircraft; and aerodynamics, structures and materials, propulsion, artificial intelligence, and advanced computational simulation are some of the traditional and newer scientific and engineering disciplines that are being studied to find new challenges and opportunities in technology that could result in aircraft capabilities not yet defined.

The success of future national programs to explore and exploit space depends, in large measure, on advances in NASA's Space Research and Technology program. The program focuses on long-term, high-payoff research and technology development to provide the capabilities required to meet national goals for space, and to maintain U.S. leadership and security in space. To facilitate the transfer of technology developed, many of the program's activities are conducted jointly with other government agencies, U.S. industry and universities.

Aeronautics

The Aeronautics Research and Technology program places emphasis upon the initial steps in the research and development process, recognizes the common civil and military utility of aeronautical technology, and capitalizes on the synergism between aeronautical and space technologies and capabilities. Elements in the program include disciplinary research and vehicle-specific research.

Disciplinary Research and Technology. NASA's disciplinary research and technology activities are aimed at establishing and maintaining a solid technology base from which new ideas and concepts can emerge that will lead to advanced aeronautical development. The research activities endeavor to

improve understanding of basic physical phenomena, and to develop new concepts in primary aeronautical technical disciplines that include fluid and thermal physics, materials and structures, propulsion, controls and guidance, human factors, and information sciences.



Computational Fluid Dynamics (CFD) flow field solution for the F-16 aircraft, generated by the Numerical Aerodynamic Simulation (NAS) system at Ames Research Center.

New techniques in the discipline of computational fluid dynamics were used to calculate the stream trace lines over an F-16 high-performance aircraft configuration. Use of these techniques will allow the identification and improvement of separated flow regions that might lead to aircraft stall and dynamic instability.

The world's most powerful supercomputer facility, the Numerical Aerodynamic Simulation (NAS) system, became operational and was made available to scientists and engineers throughout the United States.

Because they are lighter and stiffer than conventional metallic materials used in aircraft structures, composite materials are used increasingly in airframe designs. A breakthrough in composite structures research occurred with the fabrication of a geodesic stiffened compression wall panel that is about 30 percent lighter than a skin/stringer aluminum structure, and 40 percent cheaper. Also, a new approach was developed to fabricate strong, tough, ceramic composite structures that are capable of withstanding high temperatures.

Propulsion research focused on analytical and experimental work in the areas of high-speed fluid flows, chemically reacting and mixed fluid flows, turbomachinery internal aerodynamics, and high-speed inlet and nozzle aerodynamics. An analytical model was used to study flow fields in a high-speed fan stator, high-speed, counter-rotating propellers,

and in the first stage of the Space Shuttle Main Engine fuel turbine.

NASA and the FAA conducted joint studies expected to result in increased capacity for the Air Traffic Control system in the United States. Also, these agencies cooperated on programs that addressed problems of lightning, wind shear, icing, and other phenomena affecting aviation safety.

Vehicle Technology. Vehicle-specific research relates to technology that has the potential to enhance the capabilities of specific classes of vehicles, such as subsonic transport, rotorcraft, high-performance military aircraft, supersonic, and hypersonic vehicles.

The United States (NASA and DOD) and the United Kingdom signed an agreement to collaborate in the development of advanced short takeoff and vertical landing (STOVL) aircraft technologies. Also, NASA and Canada agreed to test a full-scale STOVL aircraft, designated as the E-7. Wind tunnel tests of the E-7 model confirmed the viability of the design as a high-performance aircraft.

Advances in the turboprop research program included the completion of ground tests of both single- and counter-rotation propfans in preparation for flight tests to verify large-scale propeller structures, aeroelastics, and acoustics.

Reducing rotorcraft noise received special emphasis in a cooperative research program conducted by NASA, DOD, FAA, and industry. As a result, a new helicopter total system noise prediction code called ROTONET was developed and made available to industry.

The National Aerospace Plane program (NASP) is a coordinated effort between NASA and DOD to develop advanced technologies for a new generation of aerospace vehicles. These airbreathing vehicles will be capable of operating at hypersonic speeds in the atmosphere or in space as single-stage-to-orbit spacecraft. The first experimental vehicle, designated as the X-30, will validate a wide range of aerospace technologies and capabilities.

After completing more than 85 test flights, the X-29A forward-swept wing aircraft expanded its flight envelope to Mach 1.4 at 40,000 feet. Subsequently, a NASA/Air Force program was initiated to flight test the second X-29A aircraft.

The NASA/Army X-Wing Rotor Systems Research Aircraft (RSRA) was delivered to NASA's Dryden Flight Research Facility for final assembly and integration. Successful

flight testing of the X-Wing/RSRA will lead to a new generation of air vehicles that combine the best features of both helicopter and fixed wing aircraft.

Space

The Space Research and Technology program provides critical and often unique elements of the technology base that allow the United States to maintain its leadership in space activities. The program focuses on developing technology to provide more capable, less costly space transportation systems, and large space systems, such as the Space Station; enabling scientific and planetary exploration to improve understanding of the Earth and solar system; and supporting the commercial exploitation of space. Among the disciplines included in the program are propulsion, space energy conversion, aerothermodynamics, advanced materials and structures, controls and guidance, automation and robotics, and space human factors.

Earth-to-orbit propulsion research concentrated on high-performance systems and extended service life. In this area, a cryogenic engine bearing model was developed to determine cooling, lubrication, and bearing design characteristics. Another new model predicts the life of materials subjected to both low-cycle and high-cycle fatigue. Optical sensors were used to track bearing wear, and to measure turbine blade temperatures and rotor speed. Redesigned turbine blade materials demonstrated the potential to sustain up to 20 times the fatigue life of existing blade materials.

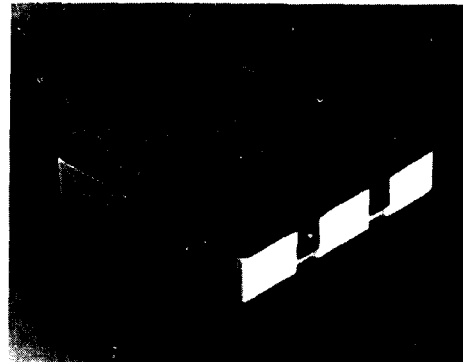
Orbit transfer propulsion research focused on developing high-performance, high-pressure, variable-thrust engines that will be stored and fueled in space. For example, technology for space-based liquid oxygen/hydrogen expander cycle engines advanced in the areas of combustion, heat transfer, materials compatibility, high-expansion ratio nozzle performance, and engine level system testing.

In the area of space energy conversion, progress continued to be made in improving the performance of solar photovoltaic (PV) cells and arrays; recent tests resulted in reduced output loss which is caused by natural radiation. Phase II of the joint DOD/DOE/NASA Space Nuclear Reactor Power System Development program (SP-100) was initiated. The

goal of the program is to provide advanced technology options that will allow higher power levels, improved system efficiency, and increased reliability and lifetime. Considerable progress was made in developing thermal management systems, consisting of heat pipes, thermal loops, and radiators. New lightweight composite materials of titanium and graphite or tungsten fibers proved feasible in the fabrication of heat pipes for use at 1000°C.

Research in the field of aerothermodynamics improves understanding of the flow phenomena of advanced aerospace vehicles. An aerospace vehicle in the concept stage that is expected to result in space-based operation is the Aeroassisted Orbital Transfer Vehicle (AOTV). Critical wind tunnel tests to assess the effects of flow impingement on various AOTV concepts were completed.

In the areas of materials and structures, significant efforts were focused on developing advanced thermal protection systems, with improved durability and high temperature capability, for use on the Space Shuttle and future space transportation systems. Research on erectable and deployable structures resulted in the development of a concept for a mobile remote manipulator system that will be used to erect large truss-type structures in space.



Impact resistant, durable ceramic thermal protection tile that will be used on the Space Shuttle and future space transportation systems.

Automation and robotics research focused on developing and demonstrating technology applicable to the Space Station, the Orbital Maneuvering Vehicle, the Orbital Transfer Vehicle, the Mobile Remote Manipulator system, geostationary satellite systems, and planetary rovers. The preliminary design and development of the Telerobotic Demonstration Facility was completed, and a sequence of demonstrations was defined for 1988.

Space human factors research concentrated on optimizing the allocation of functions between humans and computers during space missions. A new concept in computer terminals, the "Virtual Workstation," was developed that will allow scientists and engineers working from a ground base to conduct experiments and manage equipment in space by remote control.



The "Virtual Workstation," a new concept in computer terminals that will allow ground-based scientists to conduct experiments in space by remote control.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA), established in 1958, is responsible for planning, conducting, and managing civilian research and development activities in aeronautics and space. Other federal agencies, state, local, and foreign governments, as well as educational institutions and private industry, also share in NASA's programs.

NASA's mission continues to reflect the intent of Congress in creating the agency; that is, to explore space for peaceful purposes, with international cooperation, for the benefit of all humankind. Technological advances have resulted in significant economic and social benefits for the United States and other nations, and remain the catalyst for national pride, progress and achievement. The continued success of NASA's programs will allow the U.S. to maintain its leadership status in aeronautics and space.

Space Science and Applications

During 1986, NASA's space science and applications research continued to focus on the origin, evolution and structure of the universe, and on the fundamental laws that govern it. Research activities involve observation of the distant universe, exploration of the near universe, and the characterization of the Earth and its environment. Space science programs include astrophysics, planetary exploration, life sciences, and microgravity science and applications. Applications efforts include Earth science, communications, and information systems.

Space Science

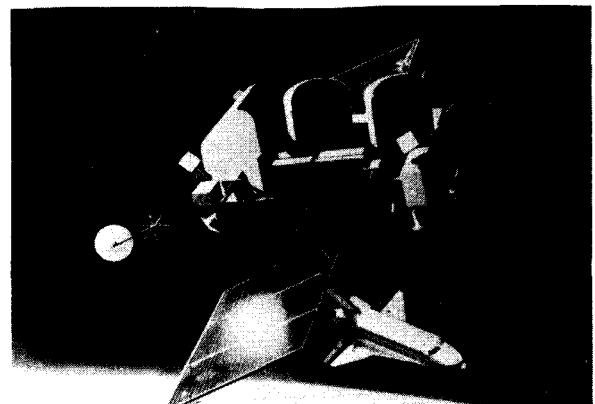
In 1986, studies of the nature of the universe and solar system continued. Voyager 2's encounter with Uranus was a major scientific event of the year.

Study of the Universe

NASA's Astrophysics program investigates the physical nature of the universe, from the

Sun to the most distant quasars, to determine the laws that govern cosmic phenomena, to understand the Sun as a star, and to learn the origins of the universe and how it will end. Many observations cannot be made through the Earth's atmosphere, so instruments for the investigations must be carried above the atmosphere into space. The goal of the program is to place in orbit four observatories, with significantly improved sensitivity, to observe objects at any wavelength in the entire electromagnetic spectrum. The Great Observatories are the Hubble Space Telescope (HST), the Gamma Ray Observatory (GRO), the Advanced X-ray Astrophysics Facility (AXAF), and the Space Infrared Telescope Facility (SIRTF). Unlike HST and GRO, AXAF and SIRTF have not yet been approved as formal programs and are undergoing preliminary study for a potential future proposal.

Hubble Space Telescope (HST). The first of the four Great Observatories, the HST is expected to be launched into space late in 1988 or early 1989. Serviced by the Shuttle and the Space Station, it will be a long-term, major observatory that will extend our vision of the universe by allowing scientists to see clearly 10 to 30 times beyond what can be seen with existing instruments. Observing the solar system, HST will provide the first images of the surfaces of Pluto and its moon, Charon; and at the edge of the universe, will determine whether a galaxy is a featureless ellipse or a beautiful spiral.



Four scientific instruments aboard the Gamma Ray Observatory will study the full range of gamma ray phenomena in the universe, observing sources at least 10 times fainter than any previous capability allowed.

Gamma Ray Observatory (GRO). Final stages of manufacturing and assembling the four scientific instruments of GRO, the second of the four Great Observatories, continued. When it is launched into space in 1990, GRO will observe objects at least 10 times fainter than any previous capability allowed, and will improve our knowledge of the origin and location of gamma rays in the universe by a factor of 50 to 100.

Solar Maximum Mission (SMM). Originally launched in 1980, the SMM remains about 75 percent operational. A major achievement of SMM during 1986 was its observation of Halley's Comet, accomplished by carefully pointing the telescope away from the Sun. Using the Coronagraph/Polarimeter, the Comet was observed when it was too close to the Sun to be investigated from the ground and from space. Currently, the observations are part of the data base being analyzed by scientists through the International Halley Watch. In addition, as the current cycle of solar activity ends and the next one begins, SMM continues to obtain an unparalleled series of observations of the Sun's corona and sunspot activity. Such a long sequence of observations has never been possible from space, and is certain to become a major resource used to test future models of the sunspot cycle. Also, selection of SMM Guest Investigators was announced, the fourth in this series. To date, more than 100 scientists from over a dozen countries have participated as Guest Investigators in the analysis of SMM data.

High Energy Astronomy Observatories (HEAO's). Data from the three HEAO's continued to provide significant contributions to our understanding of the universe. Analysis of the HEAO-2 data on clusters of galaxies revealed the presence of x-ray emission that indicates a large annual influx of matter; this discovery led to the unexpected observation of the formation of a galaxy. Analysis of data from the HEAO-3 satellite revealed that gamma rays come from the plane of the Milky Way Galaxy. This is due to the nuclear decay of approximately three solar masses of a radioactive isotope of aluminum, and is direct evidence of the continuing synthesis of heavy elements in the Galaxy. The Guest Investigator program continues to involve the astronomical community in the analysis of HEAO data.

Explorers. The International Ultraviolet Explorer (IUE) is in its ninth year of opera-

tion. More than 1,000 U.S. astronomers have used this orbiting facility to observe objects from inside the solar system extending to the edge of the universe. For several years IUE was used to observe Halley's Comet at ultraviolet wavelengths; in 1986, IUE provided additional space-based observations of the Comet and tail during the Japanese, European, and Soviet missions to its nucleus.

Infrared Astronomical Satellite (IRAS). Discoveries continue to abound from analysis of data taken by IRAS in the first survey of the sky at infrared wavelengths. Scientists from around the world conduct their research either at the Infrared Processing and Analysis Center at the California Institute of Technology or from the IRAS catalog that summarizes, in four infrared bands, the intensity of more than 250,000 objects. Copies of this catalog can be obtained from the National Space Science Data Center at NASA's Goddard Space Flight Center.

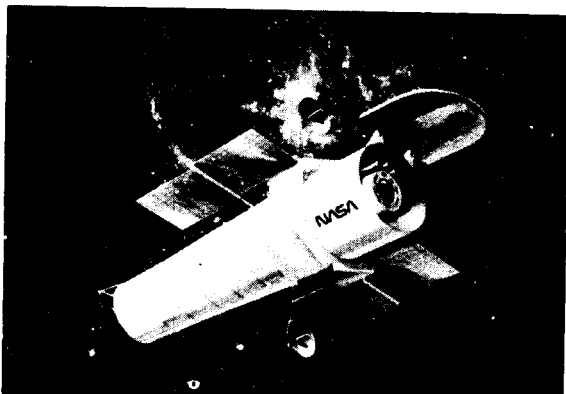
Cosmic Background Explorer (COBE). The COBE mission will investigate the earliest structure of the universe, as revealed by cosmic background microwave radiation, thought to originate a million years after the Big Bang marked the creation of the universe. From polar orbit, COBE will use instruments, cooled to within a few degrees of absolute zero, that will measure the spectrum of radiation. Early in 1986, COBE's instruments finished testing at liquid helium temperatures and integration of the spacecraft began. In the wake of the Challenger accident, extensive replanning took place, and, by the end of 1986, designs were prepared for modifications that would allow launch of COBE using a Delta launch vehicle rather than the Shuttle.

Explorer Platform. A reusable spacecraft bus for Explorer payloads, known as the Explorer Platform, was started based on the multi-mission modular spacecraft used for the Solar Maximum Mission and the Landsat missions. This spacecraft bus will be compatible with both the Shuttle and Delta launch vehicles. The first payload, the Extreme Ultraviolet Explorer (EUVE), is under development at the University of California at Berkeley. It will be launched on an 18-month mission scheduled for late 1991, and will conduct the first high-sensitivity survey of the sky at wavelengths between ultraviolet light and x-rays. Upon completion of the EUVE mission, the Shuttle will rendezvous with the Explorer Platform and replace the EUVE

payload with the X-ray Timing Explorer (XTE). The XTE mission will monitor changes in the x-ray luminosity of black holes, quasars, and x-ray pulsars; and will investigate physical processes under extreme conditions, as revealed by variations in time-scales as short as microseconds and as long as years.

SOLAR-A. Planned by a joint Japanese/U.S. team, the SOLAR-A mission will study solar activity using a payload containing two critically important experiments. One will be built by the Japanese, and the other, a soft x-ray telescope, will be built by a joint Japanese/U.S. team. Through an Announcement of Opportunity released by NASA in the spring, U.S. participants were chosen in the fall of 1986. The mission will be launched in 1992 from the Kagoshima Space Center, and will be operated by joint Japanese/U.S. science teams from a control center in Japan.

Advanced Technology Development. Advanced technology development continued for the remaining two space-based Great Observatories, the Advanced X-ray Astrophysics Facility (AXAF) and the Space Infrared Telescope Facility (SIRTF). These preliminary



The proposed Advanced X-Ray Astrophysics Facility would be 100 times more powerful than the HEAO-2 mission for detecting X-rays from celestial objects, and would provide images almost 10 times sharper.

studies will contribute to our knowledge of the development requirements of these potential future projects. AXAF will examine x-rays from celestial sources with a high-resolution, x-ray telescope comprised of nested grazing-incidence mirrors. SIRTF will allow astronomers to make the most sensitive observations of infrared radiation from stars, planets, and other infrared sources in the universe. Both facilities will help answer fundamental questions in astrophysics and astronomy.

Spartan. Carrying instruments to observe Comet Halley, the second Spartan and mis-



The proposed Space Infrared Telescope Facility would observe infrared radiation from a variety of sources in the universe, with a thousand-fold increase in sensitivity.

sion support systems, designed to release and recapture Spartan subsatellites, were destroyed during the Challenger accident. In addition to rebuilding the Spartan and supporting systems, the program is developing payloads for future Shuttle flights. The next Spartan spacecraft and supporting systems will be ready for flight in early 1988.

Gravity Probe-B (GP-B). Einstein's General Theory of Relativity predicts the effects of gravitation manifested at relativistic velocities. Although his theory is essential to understand phenomena, such as the large-scale structure of the universe, very few quantitative tests of it have been conducted. By observing gyroscopes in Earth orbit, GP-B will provide new, highly precise tests of the theory. According to the theory, a small drift will be induced in the gyroscopes due to the rotation of the Earth's gravitational field as the Earth rotates. A phased approach to the technically challenging mission is being implemented that stresses ground-testing of the system design for GP-B; ultimately, the testing will lead to flight-testing on the Space Shuttle.

Roentgensatellite (ROSAT). ROSAT, a cooperative x-ray astronomy project of the Federal Republic of Germany and the United States, is scheduled for inclusion on a Space Shuttle mission in 1994. Concurrently, efforts are un-

derway to launch the spacecraft on an expendable launch vehicle by 1989 or 1990. The U.S. instrument, the High Resolution Imager, has been produced, and will be shipped to Germany early in 1987. Development of the ROSAT Science Data Center continues at NASA's Goddard Space Flight Center.

Solar System Exploration

Cometary Studies. During 1985 and 1986, the appearance of Halley's Comet was the focus of unparalleled global scientific study from the ground, Earth orbit, Venus orbit, interplanetary space, and from within the Comet itself.

The various activities in space were coordinated by the four space agencies, ESA, Intercosmos, ISAS, and NASA, through the Inter-Agency Consultative Group (IACG). Coordination of activities of ground-based observers was provided by the International Halley Watch (IHW).

The single goal of the IHW and IACG was to maximize the scientific results of all mission efforts to explore Halley's Comet from ground and space. The obvious success of this unique endeavor should serve as an example for future cooperative scientific programs.

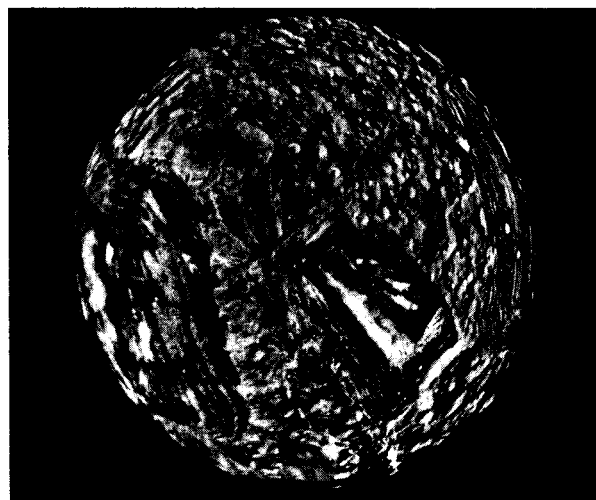
Although NASA did not send a probe directly to intercept Halley's Comet, it was studied intensively by U.S. scientists on the ground, and by aircraft, rockets, and existing NASA spacecraft. Also, U.S. scientists were involved in missions of ESA's Giotto, Intercosmos' Vega I and II, and Japan's Suisei and Sakigake that tracked the Comet.

The International Cometary Explorer (ICE) performed the most complicated orbital maneuvers ever conducted by a spacecraft when it encountered Giacobini-Zinner on September 11, 1985; also, in March 1986, it observed Halley's Comet from a distance of 35 million kilometers.

The International Halley Watch (IHW) selected scientists and organized worldwide networks of over 1,000 professional astronomers in 51 different countries that assured continuous international monitoring of the Comet by every possible technique, and at all wavelengths, accessible from the ground. As observation of Halley's Comet continues, the data acquired is being reduced and prepared for inclusion in the general Comet Halley Archives that will contain all calibrated ground and space data from the 1986 apparition.

Targeting a spacecraft to the Comet's nucleus is a major problem because the nucleus is hidden by gas and dust in the coma. The position of the nucleus of Halley's Comet was obtained from Earth-based IHW observations with an accuracy of about 500 kilometers. The reduction of this uncertainty, essential for Giotto's precise targeting, was achieved by the Pathfinder project, an historic example of international collaboration. The project involved two Soviet Vega spacecraft that encountered Halley's Comet, and provided ESA's Giotto's spacecraft with a more accurate location of the Comet's nucleus on its subsequent encounter. NASA's Deep Space Network supported the effort by tracking the Vega spacecraft using precise L-band Very-Long-Baseline Interferometry navigation techniques that allowed a flyby distance of 600 kilometers, with an uncertainty of only 40 kilometers.

The probes sent by ESA, Intercosmos and ISAS provided detailed "snapshots" of the Comet. Concurrently, NASA's ground-and space-based programs gave an overview of the global properties of the Comet and its long-term evolution. The combination of these two approaches should result in the most comprehensive Comet study possible at this time.

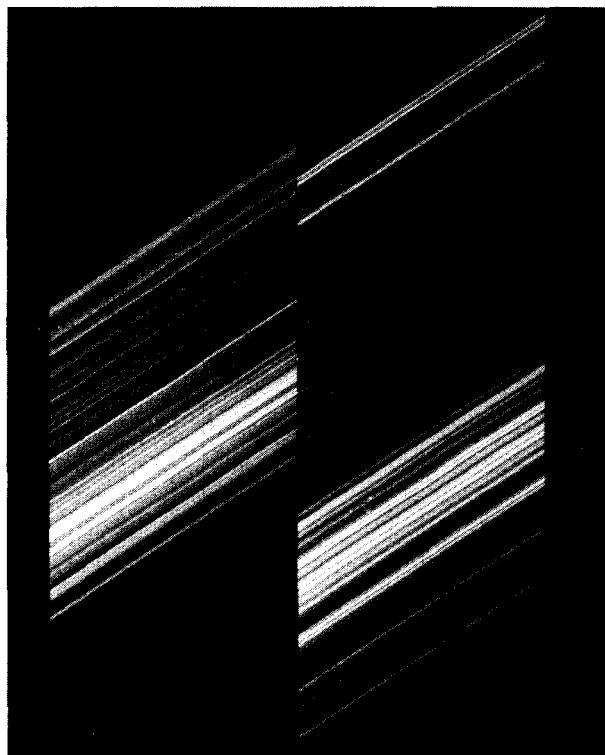


Uranus' moon, Miranda, taken from Voyager 2 spacecraft on January 24, 1986.

Voyager at Uranus. In January 1986, Voyager 2 became the first spacecraft to fly past Uranus, transmitting planetary data and over 7,000 images of that planet, its rings, and moons. In August 1989, the spacecraft will reach Neptune, its final planetary destination, and examine its large moon, Triton.

Voyager 2 discovered 10 new moons surrounding Uranus, bringing the total of identified satellites to 15 that range from 40 to 1,610 kilometers in diameter. Of the five largest moons, Oberon and Umbriel appear to have the oldest surfaces. The moons have numerous large impact craters and little evidence of surface changes in their recent geological past. Titania has a number of small craters and an extensive series of fault scarps. Ariel appears to have the youngest surface, with faults and possible evidence of ice flows. Miranda, the smallest of the large satellites, has the most amazing topography, with undulating cratered plains and canyons 10 to 15 kilometers deep and slopes 20 kilometers long.

Voyager 2 discovered two new rings of Uranus, for a total of 11 known dark, narrow rings. Although fine dust occurs in the rings, most of the ring particles are several centi-



Two slices of Uranus' epsilon ring are shown in a computer-constructed image created from data obtained by Voyager-2's photopolarimeter. The disparity in the size of the two slices illustrates the accordion-like nature of the ring, which seems to expand and contract as it orbits the planet.

meters in diameter. Also, the spacecraft revealed that the helium abundance in the atmosphere is similar to that on Jupiter and Saturn. It was confirmed that Uranus has an intrinsic magnetic field that is offset by 60 degrees from the planet's rotational axis; and

an auroral region surrounds the magnetic pole on the dark side of the planet. Voyager 2 measured the planet's rotation rate at slightly more than 17 hours.

Due to low levels of light, the long distance that communications signals traveled, and problems aboard the eight-year-old Voyager spacecraft, the Uranus flyby was an engineering challenge. Many modifications were made to the spacecraft in flight, as well as to data processing systems on the ground that included NASA's deep space communications stations in California, Spain, and Australia. The Australian station was situated to receive most of the data from the time of the spacecraft's closest approach to Uranus, and was supplemented by the Parkes radio astronomy antenna.

Pioneer Venus. Early in 1986, the Pioneer Venus Orbiter spacecraft, now in its seventh year of operation, obtained unique images of Comet Halley when the Comet was "behind" the sun and unobservable from Earth. At that time, the planet Venus was relatively close to the Comet. By reorienting the spacecraft's Ultraviolet Spectrometer instrument, it was able to make daily observations of the Comet's behavior over a five week period. Data on the chemical composition of the Comet's atmosphere and rate of water evaporation from its nucleus were obtained, and the huge cloud of hydrogen gas which comprises the outer layer of the Cometary coma was mapped. Measuring approximately 20 million miles in diameter, the cloud is 15 times larger than the Sun; and observed changes in its brightness and shape indicate variations in solar radiation pressure.

As the spacecraft orbit continued to evolve, other instruments on the Pioneer Venus Orbiter made important new measurements of the solar wind interaction with Venus. The data gathered are particularly important because this was a period of minimum solar activity. Due to the absence of a planetary magnetic field, the interaction of the solar wind with Venus was found to be comet-like. One consequence is that plasma "tail" structures extend outward from the nighttime ionosphere of Venus, appearing much like cometary tail rays.

The Interplanetary Medium. Pioneers 10 and 11 and Voyagers 1 and 2, continued to measure the properties of the interplanetary medium in the outer solar system. Pioneer 10 is now 38 astronomical units from the Sun. It

is well outside the orbit of Neptune and the outer boundary of the solar system. Pioneer 11, traveling in the opposite direction from Pioneer 10, is now 22 astronomical units from the Sun, between the orbits of Uranus and Neptune. Because of declining power levels available from thermoelectric generators aboard the spacecraft, power-sharing among the Pioneer instruments was initiated. The primary scientific goal of Pioneers 10 and 11 is the search for the heliopause, the interaction boundary between the solar wind and interstellar space.

Pioneer 11 played an important supporting role in Voyager 2's encounter with Uranus. The spacecraft used its instruments to monitor solar wind conditions throughout the encounter period. At this time, Pioneer 11 was crossing the orbit of Uranus six astronomical units beyond Voyager 2's encounter point.

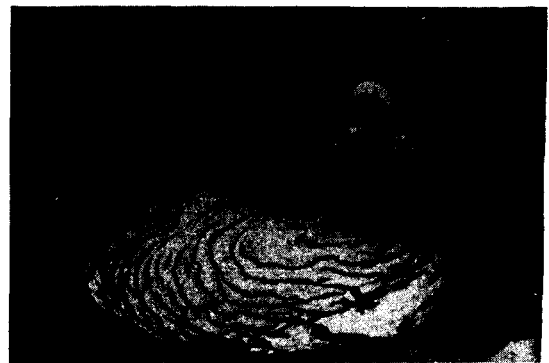
Galileo In May 1986, Galileo's mission to Jupiter was scheduled for launch; however, as a result of the Challenger accident, the launch will not occur before late 1989. Also, since the Centaur upper stage program was cancelled due to Shuttle safety concerns, a reevaluation of Galileo's launch and trajectory profiles has taken place. Currently, no upper stage capable of placing Galileo on a direct trajectory to Jupiter is available. Present plans call for a Shuttle/Inertial Upper Stage (IUS) launch of the spacecraft on an initial trajectory to Jupiter, followed by two passes around the Earth that will allow sufficient energy to reach Jupiter.

Ulysses. Ulysses was scheduled for a May 1986 launch on the Shuttle/Centaur. Like Galileo, the combination of the Challenger accident and Shuttle/Centaur cancellation has forced a reevaluation of the mission. However, unlike Galileo, and because of Ulysses' smaller mass, a plan was developed that maintains the same transit time to the higher latitudes of the Sun as the planned 1986 mission. Ulysses will be launched in September 1989 or in October 1990 using the Shuttle/IUS system, with an energy augmentation derived from a Payload Assist Module. This additional energy will allow use of the massive Jovian gravity to reach higher latitudes of the Sun.

Magellan. Active development continued on the Magellan mission to Venus that will use a polar orbiting, radar-equipped spacecraft to map the cloud-shrouded surface of the planet. The objectives of the mission are to determine the geology of the surface, and to under-

stand how Venus has evolved compared to other bodies of the inner solar system. The Challenger accident resulted in delaying the launch date of Magellan from 1988 to 1989. Designs for the spacecraft and radar instrument were completed, and significant progress was made in fabricating the flight hardware.

Current plans call for the Magellan spacecraft to be launched in April 1989 by the Shuttle/IUS, and its encounter with Venus is expected in August 1989. Nearly the entire surface of the planet will be mapped in high-resolution radar imagery from August 1989 to May 1990. The images obtained will be an improvement, by a factor of 10, over those obtained by the Soviet Venera 15 and 16 missions in 1983 and 1984 that covered less than 20 percent of the planet.



Scheduled for launch in 1990, the Mars Observer spacecraft will study the atmosphere, surface geochemistry, interior, and climate of Mars on a global scale.

Mars Observer. The Mars Observer spacecraft manufacturer, RCA, and the contractor for the upper stage, the Orbital Science Corporation, were chosen. Also, the geoscience and climatology experiments were selected, along with the group of scientists who will monitor instrument development and preparations for the data analysis phase. To achieve scientific objectives, and to provide high resolution images for any future advanced missions to Mars, a camera will be added to the payload. Scheduled for launch in August 1990, the mission will last one Mars year (687 Earth days) during which surface and atmospheric changes will be observed over all four seasons.

Flight Missions Support. In 1986, Ground Data Systems tests to support Voyager's encounter with Uranus, and the planned launches of the Ulysses and Galileo spacecraft were completed. Although the launches were postponed, Voyager's encounter with

Uranus was an extraordinary success. Acquisition and processing of significant amounts of rare data from the encounter, both in real-time and batch processing modes, by the Mission Control and Computing Center (MCCC), were accomplished without difficulty. Images produced by the new Multi-mission Image Processing Laboratory taken from observations of the planet, its rings, and its moons were spectacular and are of unique scientific value. Also, the MCCC supported the Giotto encounter and Pioneer Venus Orbiter observations of Halley's Comet. Pioneer Venus produced the only data obtained when the Comet was most active, closest to, and behind the Sun. Significant design advances were made in the new Space Flight Operations Center to produce multi-mission Ground Data Systems that will be more cost efficient and scientifically productive.

Advanced Programs and Planning. The planetary "Core Program" recommended by the Solar System Exploration Committee in 1983 included two new classes of spacecraft: Planetary Observers for near-Earth missions and Mariner Mark II spacecraft to explore the outer solar system. Planning continued for a future start of the first Mariner Mark II mission, the Comet Rendezvous Asteroid Flyby (CRAF) mission. CRAF will make a close flyby of an asteroid and then rendezvous with a comet for extended observation and study. During 1986, proposals for scientific investigations and instruments for the CRAF mission were evaluated, and a tentative flight payload was selected. A second potential Mariner Mark II mission, Cassini, would consist of a Saturn orbiter mated with an ESA-developed Titan entry probe. During 1986, science teams from ESA and NASA conducted joint studies of this possible mission.

Life Sciences

The Life Sciences program is involved in all major aspects of NASA's activities in space exploration. The program has two major goals, derived from NASA's charter: to promote health and productivity in manned space flight, and to study biological processes and life in the universe. The Life Sciences program extends from basic research to applied clinical practice. Major areas of research include Space Medicine, Gravitational

Biology, Global Biology (Biospherics), Exobiology, and Controlled Ecological Life Support Systems. During 1986, substantial progress was made in each of these areas of research.

Space Medicine. Through basic and applied research, clinical studies, and flight programs, NASA is investigating the nature and mechanisms of adaptation, deconditioning, and inherent risks resulting from exposure to space flight. In turn, this knowledge helps scientists to develop protective measures and safety procedures needed to ensure the health and productivity of crews during long-term missions. The program will develop protective measures for repeated exposures to the space environment.

In the area of Space Medicine, clinical characterization and the time course of motion sickness have been described. Working with the Space Biomedical Research Institute at Johnson Space Center, NASA expects to expedite processes that investigate countermeasures to space sickness and identify susceptible individuals.

Including Congressman Bill Nelson in the crew of STS 61-C gave NASA's Life Sciences Program an opportunity to expand the scope and depth of medical experiments. This mission investigated operationally important issues related to human capabilities in space, such as space motion sickness, echocardiography, inflight treadmill stress tests, changes in total body water during space flight, and eye-hand coordination.

A Health Maintenance Facility (HMF) is being developed for the Space Station that will incorporate state-of-the-art technology and inflight medical care, and will also enable adequate exercise and health monitoring for space crews. Also, tests of physical exercise protocols for the HMF are underway. In the area of human factors and man-machine interface, a sophisticated computer modeling system is under development that is based on anthropometric measurements made in space flight and on the ground. This system will accelerate design of work stations, assess work conditions, and determine appropriate workloads for space crews.

Gravitational Biology. The goal of the Gravitational Biology program is to understand how gravity affects and shapes life on Earth. This program uses weightlessness as a tool to understand life and its processes; by understanding how the space environment affects plant and animal species, the human ability

to use and explore space can be greatly enhanced. Both flight- and ground-based research in the gravitational biology area provide significant information on the biological significance of gravity. Also, the role of calcium as a gravity-sensing element in both plants and animals has been significant.

Animal research has emphasized modeling the gravity-sensing systems of animals, understanding mechanisms that control bone formation and loss, and identifying mechanisms that lead to normal muscle development and atrophy when gravitational loading is removed. Analysis of otoconia (crystals that form the sensory mass in the inner ear) in rats flown on Spacelab 3 indicate that crystal formation is affected by gravity and that, under near-weightless conditions, a number of small, potentially immature crystals were formed. The significance of this finding has yet to be determined. This flight also showed that bone strength is reduced in growing animals which suggests that gravity loading is essential to the development of normal bone. Also, significant changes in muscle were observed. Rodents flown in space lost up to 40 percent of mass in leg muscles which are normally used to oppose gravity.

Biospherics. The goal of the Biospherics Research program is to understand how biological and planetary processes interact. This is done in conjunction with the environmental effects of human activity, and how these processes affect the long-term habitability of the Earth. Currently, efforts are concentrated in specific research projects that include wetlands, along the eastern part of the United States; temperate forests, represented by Sequoia National Park; tropical forests, represented by the Amazon forest; and global studies that concentrate on biogeochemical models. In addition, a new effort that applies remote sensing technology to the solution of global health problems will be developed. This research program is using existing data banks, remote sensing techniques, and field research to create mathematical models that predict biospheric behavior under a given set of perturbations. These models are integrated with mathematical models of planetary behavior, and they are continually evaluated for accuracy and modified when necessary. By ensuring that undesirable consequences of biospheric change do not adversely affect the habitability of the Earth, the Biospherics Research program has impor-

tant implications for the future of the terrestrial ecosystem.

Exobiology. The Exobiology program seeks to understand the origin, evolution, and distribution of life in the universe, focusing on six major areas: cosmic evolution of biogenic compounds, prebiotic chemistry, early evolution of life, evolution of advanced life, solar system exploration, and the search for extraterrestrial intelligence. The prime focus of exobiology research is on investigating the characteristics and life-promoting or life-threatening events that dominate important evolutionary stages. This research elucidates the role of the biogenic elements, the main constituents of living matter, and the biogenic compounds in solar system formation, planetary development, and the emergence and impact of life.

Recent accomplishments within the program include the discovery of precursors of biologically important organic molecules in the interstellar medium. Analysis has shown a direct link between organics in the interstellar medium and those found in primitive solar system bodies. These results add to the available evidence that life might exist elsewhere in the universe. It also indicates that life may be an integral part of the origin and evolution of the stars and planets. Concurrently, planetary exploration and ground-based planetary environment simulations are adding to our awareness of conditions required for the origin and evolution of life.

Controlled Ecological Life Support System (CELSS). A spacecraft system that continually recycles the solid, liquid, and gaseous materials essential for human life is the goal of the CELSS Program. The main focus of CELSS research has been on techniques for growing higher plants and algae, processes for recycling solid and liquid wastes, and system interactions in biological life support systems.

Laboratory results show that desired specifications can probably be met or exceeded. In terms of usable dietary calories divided by the photosynthetically active light energy needed to produce them, energy conversion efficiencies in the 7 to 9 percent range were obtained for wheat, potatoes, and soybeans; efficiencies approximately twice as high were measured for two kinds of algae. Under the CELSS Breadboard Project for bioregenerative life support, a chamber designed to test techniques for growing plants in a "closed" environment was completed.

Applications

Communications

NASA has implemented a multifaceted communications satellite program to meet foreign competition and maintain U.S. pre-eminence in the global marketplace. One element in the development of this program is the Advanced Communications Technology Satellite (ACTS) Project, scheduled for launch in 1990. ACTS technology will contribute to future domestic and global satellite networks. Another major thrust in NASA's communications program is the partnership with industry in a mobile national satellite service. Recently, a significant milestone was reached with the allocation of domestic frequencies by the Federal Communications Commission (FCC). This first generation commercial system will provide communications to and from trucks, boats, and airplanes. It will create a totally new service and hardware industry, and improve the productivity of many U.S. communications industries. Launch of the first spacecraft for this system is expected in 1990 or 1991. The Search and Rescue system, which locates aircraft and vessels in distress, is gaining worldwide acceptance. It is credited with saving more than 675 lives since its inception. NASA continues to develop technologies needed to use the geosynchronous arc and spectral frequencies effectively.

Advanced Communications Technology Satellite (ACTS). In 1986, the ACTS project moved closer toward its goal of a spacecraft launch from the Shuttle by late 1990.

In 1986, a steerable antenna was added to extend the ACTS coverage to states and areas outside the contiguous 48 states, such as Alaska, Hawaii, and South America. The cost of the augmentation has been assumed by RCA, the prime contractor on the ACTS. In addition, a joint NASA/Air Force effort was initiated to develop an optical payload that will demonstrate laser intersatellite communications technology. This optical payload will allow laser communications between the ACTS and ground terminals, low Earth orbiting vehicles, such as the Space Shuttle and the Space Station, and other satellites in geosynchronous orbit, such as the Tracking and Data Relay Satellite.

Mobile Satellite. The joint mobile satellite program with U.S. industry and other government agencies will provide two-way satel-

lite-assisted communication with cars, trucks, trains, boats, and aircraft within the next four to six years. Such a system, offering nationwide voice and data communications, is especially important for mobile users in rural and remote areas of the United States. This system would also complement existing and planned urban terrestrial service, energy, mineral, and forestry operations; business and commercial endeavors; emergency and disaster communications; and wide-area law enforcement. By mid-1985, the FCC had received 12 applications to build a mobile satellite service. In mid-1986, the FCC allocated L-band frequencies to domestic mobile satellite service, removing a major barrier to implementation. Currently, the FCC is in the process of formulating service guidelines and selecting a system.

NASA is developing and testing the power, spectrum, and orbit-efficient technologies critical to the success of high-capacity, future mobile satellite systems. In direct response to the President's policy on the commercial use of space, the system will create new hardware markets, business and service industries in the United States, and counter growing foreign competition, such as the Japanese launch of an experimental mobile satellite scheduled for 1987.

Search and Rescue. The COSPAS/SARSAT system completed its first year of regular operation. Its success has stimulated participating governments to draft a new agreement which reflects a strong and continuing commitment to the program. World-wide interest in this rescue system began with the endorsement of the 406 MHz frequency as the primary frequency for the Emergency Position Indicating Radio Beacon (EPIRB) that will be used for the future Global Maritime Distress and Safety System. There is continual development of world-wide standards for Emergency Locator Transmitters (ELT's) operating in the same frequency band. In addition, research and development is continuing on techniques and technologies to reduce false alarm rates, improve location accuracy and provide near instantaneous detection.

Advanced Planning. In close coordination with industry and advisory groups, NASA is developing plans to address future space communications needs, and the ever increasing demand for communication bandwidths. Currently, there is little distinction between the communications technology requirements of NASA's future planetary missions and Space

Station operations and those of the U.S. industrial space community as a whole. Technologies being investigated for possible future development and application include optical communications for holographic image transmission in space robotics; communications links to support space travel, and lunar and planetary exploration bases; and large, multibeam antennas with frequency reuse factors of 5 to 20 or more. This will conserve spectrum and allow growth of future mobile satellite systems. Also, technologies that could implement an on-orbit antenna array are being studied. They could be used within the Space Station complex to test and calibrate large antennas in a near zero-gravity space environment.

ATS-3. ATS-3 (Advanced Technology Satellite) continued to support the National Science Foundation, National Oceanic Atmospheric Administration, Department of Defense, Department of Interior, Drug Enforcement Administration, several universities, state and local governments, and a number of domestic and international disaster relief organizations. Through satellite voice and data links in science and communication application experiments, support is provided to North and South America, most of the Atlantic Ocean, and a large part of the eastern Pacific, including Hawaii and Antarctica.

Environmental Observations

The Environmental Observations program continues to provide more information about the terrestrial atmosphere and environment which, in turn, increases our understanding of the processes that affect them.

Upper Atmosphere. During 1986, NASA completed its portion of a comprehensive report assessing the current state of knowledge of the processes that control the distribution of atmospheric ozone and its susceptibility to change caused by natural and anthropogenic perturbations. The assessment was co-sponsored by NASA, FAA, NOAA, the World Meteorological Organization, the United Nations Environment Program, the Commission of the European Communities, and the Federal Republic of Germany.

The infrared data collected by the ATMOS instrument, which flew on Spacelab 3, was analyzed and archived. This is the most comprehensive set of data ever collected on the

chemical composition of the upper atmosphere. Chemical species, predicted to be present in the atmosphere but never before observed, were measured quantitatively.

In collaboration with NOAA and the Chemical Manufacturers Association, NASA co-sponsored a scientific workshop to design a network of ground-based remote sensing instruments to monitor long-term changes in the chemical composition and physical structure of the stratosphere. Currently, aspects of the plan are being implemented.

NASA, NOAA, NSF, and the Chemical Manufacturers Association co-sponsored a group of scientists that conducted research at McMurdo Station in Antarctica. While in residence, the group used remote sensing techniques and balloon-borne instrumentation to study the so-called ozone hole that has been observed by both ground and satellite instrumentation. The results of this expedition will help to identify the cause of the ozone hole. It will also determine if the Antarctic hole is a precursor of changes elsewhere on the globe.

Work continued on the observatory and ground data handling segments of the Upper Atmosphere Research Satellite (UARS) program. Remote sensing instruments on the satellite will perform measurements of the energy input, chemical composition, and dynamics of the stratosphere and mesosphere. UARS is a critical component of NASA's efforts to understand the upper atmosphere well enough to assess its susceptibility to chemical change. The UARS is scheduled for launch in 1991.

In 1985, NASA completed the second Global Tropospheric Experiment/Chemical Instrumentation Test Evaluation (GTE/CITE-2) project, an aircraft-based effort to validate sensitive instruments required to study global tropospheric chemistry. The objectives of the GTE are to assess the role of tropospheric chemistry in biogeochemical cycles; the troposphere's role as the ultimate source for chemical species in the stratosphere; and the contribution of tropospheric ozone compared to total ozone content in the atmosphere.

Interdisciplinary Research. NASA continued its Interdisciplinary Research program in Earth Science to investigate and understand long-term physical, chemical, and biological changes in the Earth's environment. Based upon their importance to science, areas that have been selected for new investigation include research to understand the

origins and consequences of increases in atmospheric concentrations of methane; to understand the extent to which changes are taking place in climatologically important properties of land surfaces; and to develop a better understanding of the magnitude and variability of oceanic carbon fluxes on a basin to global scale. Under existing programs, complementary investigations are being conducted in the areas of atmospheric dynamics and radiation, oceanic processes, global biology, tropospheric chemistry, climate, and land processes.

Geodynamics. Geodynamics involves the study of the solid Earth, its global gravity and magnetic fields, the movement and deformation of its crust, and its rotational dynamics. This research contributes to our understanding of earthquakes, the evolution of the Earth, and the interaction between the solid Earth, the oceans and atmosphere. Over 30 countries participate in NASA's geodynamics research, and there is intergovernmental cooperation between NSF, USGS, NOAA, and DOD. The Crustal Dynamics project involved 20 investigators from Australia, Brazil, Canada, Chile, China, the Federal Republic of Germany, France, Italy, Mexico, the Netherlands, New Zealand, Peru, Spain, Sweden, Switzerland, the United Kingdom, and Venezuela. In 1986, joint projects and programs included measuring tectonic plate motion and Earth rotation, using fixed and mobile laser ranging systems, with Italy, France, Israel, and Mexico; using techniques of Very Long Baseline Interferometry, with Japan and Italy; lunar and satellite laser ranging operations, with Australia; data exchanges, with China; and a study of earthquake hazards in the Caribbean Basin, with several nations.

Operational Meteorological Satellites. Due to a premature shutdown of the Delta launch vehicle's main engine, the GOES-G launch attempt on May 3, 1986 ended in failure. To complete the operational complement of two geostationary satellites, the GOES-G satellite was expected to join the GOES-6 satellite in orbit. The GOES-6 satellite will continue to operate in a mid-country geosynchronous orbit until GOES-H, the last of the current generation of geostationary satellites, is launched in February 1987. The GOES-H satellite will be stationed at 75 degrees west longitude, providing coverage for the eastern United States, and GOES-6 will be moved

back to 135 degrees west longitude to provide west coast coverage.

In September 1986, the NOAA-10 satellite was launched into a polar orbit from Vandenberg Air Force Base. It will replace the NOAA-6 satellite and provide early morning global coverage. It is anticipated that NOAA-H will replace NOAA-9 in December 1987.

The current series of NOAA satellites are launched on Air Force Atlas-E expendable rockets. In 1986, plans were initiated to launch these satellites on Air Force Titan-II vehicles beginning with the NOAA-K satellite, and possibly with the NOAA-I satellite.

Climate Research. The primary focus of the Climate Research program is to understand the physical processes that influence climate. During 1986, the Earth Radiation Budget Experiment (ERBE) received and processed data from the Earth Radiation Budget Satellite, launched in October 1984, and the ERBE instruments aboard the NOAA-9 and NOAA-10 operational meteorological satellites, launched in December 1984 and October 1986, respectively. Thus far, the international science team has devoted most of its efforts to validation of the global ERBE data products. It is expected that ERBE will help establish the role of clouds in the Earth's radiation budget, particularly in response to increasing concentrations of trace gases such as carbon dioxide and chlorofluorocarbons.

Uncertainties about the geographical and temporal distributions of clouds are recognized as major impediments to improved climate prediction. In 1986, the International Satellite Cloud Climatology Project (ISCCP) continued its third year of operation, collecting and processing data on the global distribution of cloudiness. The data was obtained from an international array of operational polar-orbiting and geostationary meteorological satellites. NASA plays a central role in the ISCCP through its support of the Global Processing Center that serves as the hub of international climatology operations.

Final planning was completed and implementation is underway for Project FIRE (First ISCCP Regional Experiment), a multi-agency research program located at NASA's Langley Research Center. The program seeks a better understanding of the roles played by physical processes in controlling life cycles of climatically important cloud systems. Also, it attempts to improve the parameterization of clouds in climate models, and to contribute to

the validation, on a regional basis, of the ISCCP. In October 1986, the first field experiment was conducted by the university-government FIRE science team. It focused on cirrus cloud systems that, along with marine stratocumulus cloud systems, are believed to be particularly important to the Earth's radiation budget climate.

Global Scale Atmospheric Processes. Advanced remote sensing techniques, both active and passive, are being developed for satellite observations of the Earth's atmosphere. The active remote sensing techniques apply to both Laser Interferometric Detection and Ranging (LIDAR's) radars and to sensing atmospheric parameters. Emphasis is placed on the application of laser techniques, tested on aircraft platforms during 1986, that remotely observed atmospheric temperature, pressure, and moisture profiles. A logical progression of development of LIDAR instruments starts from testing on aircraft platforms, and Shuttle pallets, to using on low or high inclination Space Station polar platforms. Development of additional laser techniques, using coherent LIDAR's to observe wind profiles, continues. In 1986, a preliminary design study for placing a coherent LIDAR wind sensor on the Shuttle was completed. This study provided a positive indication of the maturity of the technology, and allowed serious consideration of its use in a satellite global wind sensor.

In concert with the capabilities of computational hardware, mathematical techniques to model physical processes in the Earth's atmosphere have improved. Studies of modeling techniques to improve use of satellite observations for large-scale atmospheric processes, completed and reported in 1985 and 1986, demonstrated that satellite observations of global wind profiles will dramatically improve our understanding of large-scale atmospheric processes. The improved capability to observe atmospheric motions and atmospheric moisture will increase our understanding of a portion of the hydrological cycle.

The Geophysical Fluid Flow Cell (GFFC). The Geophysical Fluid Flow Cell, an experiment to model fundamental fluid dynamical processes representative of stellar and planetary atmospheres, was flown as part of the Spacelab-3 payload launched in 1985. The experiment exceeded its objectives and provided a wealth of data to be analyzed over the next several years. Early analyses presented at

several scientific meetings and reported in the Journal of Science in 1986 show the utility of the experiment in identifying and studying a large variety of atmospheric motion regimes in rotating planets and stars. The success of GFFC and the large number of cases that could be studied interactively, with minor modification to the Spacelab-3 hardware, have encouraged consideration of this experiment for future Spacelab missions.

Mesoscale Atmospheric Research. In 1986, extensive field research was undertaken, such as the study of the East Coast winter storm sudden-intensification phenomenon, and the study of several storm characteristics and interactions off the shore of the southeastern United States. In the former case, NASA participated in the Genesis of Atlantic Lows Experiment (GALE) and, in the latter, supported both the Microburst and Severe Thunderstorm (MIST) and Satellite Precipitation and Cloud Experiment (SPACE). These experiments were two of the three elements of the Cooperative Huntsville Mesoscale Experiment (COHMEX).

During the COHMEX experiments, conducted in the Tennessee Valley near Huntsville, Alabama, the most extensive set of high altitude aircraft measurements of weather systems ever taken was recorded. Numerous experiments to measure the storms' visible, infrared, microwave, and lightning-produced emissions were measured. This was done simultaneously to allow future interpretation of storm intensification, rainfall rates, damaging high winds and hail, dynamic interaction between storms, and development of storms from moist, unstable environments.

During 1986, both the Bangladesh Agro-Climatic/Environmental Monitoring Project and the Fiji Storm detection and Warning System Project for the South Pacific were completed. Subsequently, the systems began routine observations.

Oceanic Processes. Spaceflight activities in the oceanography program focused on the Tropical Ocean Global Atmosphere and World Ocean Circulation Experiments, and the Global Ocean Flux Study; a number of spaceflight missions in the program are planned for launch in the early 1990's. The first of two oceanic missions in the Physical Oceanography program, the NASA Scatterometer (NSCAT) is scheduled for launch aboard the Navy's NROSS mission. The Science Working Team, comprised of successful respondents to the NSCAT Announcement of

Opportunity (AO) was selected and the scientists are actively involved in pre-launch research efforts. The second mission, the Ocean Topography Experiment (TOPEX), will be jointly conducted with the French Space Agency's POSEIDON project. The TOPEX satellite with POSEIDON sensors aboard will be launched by a French Ariane rocket in late 1991. In response to the recently issued "Request for Proposal" for the single satellite contractor, proposals from U.S. industry were received; and selection is anticipated within the next few months. Also, the AO has been issued to initiate the process for selection of the TOPEX/POSEIDON Science Working Team.

In the Ocean Productivity Program, processing Nimbus-7 Coastal Zone Color Scanner (CZCS) imagery into ocean-basin maps of chlorophyll is well underway; and the first such map covering the North Atlantic has been produced. Launched in 1978, Nimbus-7 has performed well beyond its one-year design lifetime.

Space Plasma Physics. Plasmas exist throughout the universe and occupy more than 99 percent of its volume. Space plasma physics involve the systematic study of plasma environments that can be directly sampled by balloons, rockets and spacecraft from just above the Earth's atmosphere, through the Earth's magnetosphere and the interplanetary medium to the solar atmosphere, and into the atmospheres and magnetospheres of other planets. Due to its effect on communications, power transmission, energy production, transport, and weather, the solar-terrestrial plasma environment is especially relevant to modern, technologically oriented society. Research in space plasma physics focuses on using the plasma environment as a laboratory, especially through active experiments to simulate plasma phenomena and in situ measurements of natural plasma environments.

International Solar-Terrestrial Physics program (ISTP). The National Academy of Sciences has completed a study entitled "An Implementation Plan for Priorities in Solar-System Space Physics" (National Academy Press, 1985) which proposes a systematic plan of solar and space plasma physics research until 1995. It gives the ISTP program the highest priority and support efforts to define U.S. contributions through the use of satellites, instruments, data handling and modeling. During 1986, significant planning

for the program was done with the Japanese Institute of Space and Astronautical Sciences (ISAS) and the European Space Agency (ESA). ISAS is developing the Geotail spacecraft designed to explore the geomagnetic tail of the Earth. ESA continues to develop the Solar and Heliospheric Observatory (SOHO), a solar-pointed spacecraft to measure basic physical processes of the Sun, and Cluster, a set of four spacecraft to study basic plasma phenomena that will employ multi-point measurements to resolve space and time variations near magnetospheric boundaries. A Cooperative Solar Terrestrial Research effort has begun, in which NASA will provide support for U.S. investigators on the Geotail, SOHO, and Cluster missions.

Operational Explorers. Perhaps the most cost-effective spacecraft ever launched by NASA is the 13 year old Interplanetary Monitoring Platform (IMP-8) satellite, the workhorse of Explorers. It continues to function well as the only existing monitor of solar wind interactions with the Earth's magnetosphere, and provides a crucial baseline for missions to the other planets.

The International Cometary Explorer (ICE) (the retargeted Sun-Earth Explorer-3), launched in 1977, continues to operate; from the large amount of data it generates, over 100 scientific papers per year are published. The papers cover the full range of space plasma phenomena, from collisionless shock and boundary layers to wave-particle interactions and currents along auroral field lines. In September 1985, ICE intercepted Comet Giacobini-Zinner. The research analyses conducted on the ICE data were a critical complement to the Comet Halley encounter in March 1986. In particular, the ion tail model of dual lobes of opposite polarity, separated by a neutral sheet, was validated; and dust levels were found to be several orders of magnitude less than the predicted rate. Also, ICE detected waves and energetic particles millions of kilometers upstream from the Comet.

The Dynamics Explorer (DE) spacecraft continued to provide new, unique data on ionosphere-magnetosphere interactions and auroral morphology, as well as on global airglow and ozone measurements. A special campaign of ground-based, rocket, balloon, and satellite observations was implemented between April and June 1986 in which DE was a key player. Also, Global auroral imaging of the southern pole was conducted by DE. Similar imaging of the northern pole was

conducted by the Swedish Viking polar orbiter, launched in January 1986. This campaign, called PROMIS (Polar Region and Outer Magnetosphere International Study) demonstrated the utility of making carefully coordinated measurements in the geospace environment, the core theme of the ISTP program.

During 1986, the Active Magnetosphere Tracer Explorer (AMPTE) began its extended mission phase that involved passive measurements of the inner magnetosphere. Continued analysis of observations made during the active phase provided important tests of cometary models, and information on plasma-field interactions in the outer magnetosphere. Ion composition measurements from AMPTE are especially valuable because they have demonstrated the important role of the ionosphere as a source of ions for the magnetosphere.

Sounding Rockets and Balloons. During 1986, 14 space plasma physics sounding rockets and two balloons were launched to study properties of the middle atmosphere and the auroral regions. In May 1986, a rocket was launched with two payloads that separated in flight. Forty-two different, but major elements of the mission operated flawlessly. This very successful mission provided important evidence to support the Critical Ionization Velocity effect which has implications for Cosmological and Astrophysical systems and for basic plasma physics.

Land Processes. The Land Processes Program consists of four interrelated elements: studies of terrestrial ecosystems, hydrologic cycle, continental geology, and remote sensing science. The first three represent the space-based components of classical science disciplines. The last element is the study of the physics and biology of the land surface as it relates to the interaction of electromagnetic radiation. The major focus is to conduct research in the Earth Sciences that concentrates on developing methodologies, rather than instruments and techniques for scientific or applied use.

Extensive use is made of data from operating satellite sensors, such as the Landsat Multispectral Scanner System (MSS) and Thematic Mapper (TM), the Advanced Very High Resolution Radiometer (AVHRR) on NOAA polar orbiting satellites, and sensors aboard the French SPOT satellite. Equally important are data from experiments on Shuttle flights such as the Shuttle Imaging

Radar (SIR) series, SIR-A and SIR-B, the Airborne Imaging Spectrometer, the Advanced Solid State Array Spectrometer, the Thermal Infrared Multispectral Scanner, and the L-Band Pushbroom Microwave Radiometer. The L-/C-band synthetic aperture radar, which was destroyed in the crash of the NASA CV-990 aircraft in 1985, is being replaced.

As a result of several interrelated studies, use of visible and near infrared radiances to monitor the productivity of natural biological systems improved. A simple function of selected satellite bands proved to be directly related to photosynthetic capacity and the transpiration of water vapor. This method was applied to measurements of the North American Continent during the growing season of 1982, and the results were compared to published values of ecosystem productivity. Previous studies only concentrated on the relatively simple system of the grasslands. This study extended application of the method over ecosystems as diverse as tundra, highly productive, temperate agricultural regions, and deserts. In a further test of this model, global ecosystem dynamics over a 31-month period were compared to interannual variations in atmospheric carbon dioxide. In the future, more rigorous physical modeling of diverse ecosystems will be needed.

Data on the Northern Hemisphere from 1979 to 1983, obtained by the Nimbus-7 Scanning Multispectral Microwave Radiometer (SMMR), were used to produce assessments of the extent and magnitude of seasonal snow cover. Measurements from the 18-GHz and 37-GHz frequencies were used to evaluate equivalent snow depth. These measurements were based on results from field studies and theoretical modeling of microwave emissions from snow packs. In general, microwave emissions decrease with increasing snow cover. The two-frequency approach is used to account for the effects of surface temperature variations which disrupt the snow depth and microwave emission relationship. Monthly assessments (the mean of 5 days) of Northern Hemisphere snow fields were produced for four years and the results compare favorably with the standard NOAA snow extent maps. In addition, the results are of significantly greater value because they are not subject to the errors inherent in the NOAA visual interpretation of AVHRR solar reflectance data, such as subjectivity and inability to distinguish between

snow cover and clouds; and, the SMMR data can evaluate snow depth, a capability that was not previously available from satellite observations. Considerable interannual variability in seasonal snow cover is observed in these measurements that is attributable to the dynamics of Northern Hemisphere weather patterns during winter. Knowledge of this variability is of great importance to understanding the hydrology and climatology of the Earth. It is now known that snow fields contain a significant portion of the planetary water, and the albedo of snow is much greater than that of other land materials. In addition, snow requires a considerable amount of heat to melt; therefore, the amount of snow accumulated in the winter determines, at least in part, the time required to heat up the Northern Hemisphere in the spring.

Analysis of the Earth's magnetic field, from data obtained by the Magsat spacecraft, continued to offer new insights into the structure of the Earth's crust and mantle. This information provides a better picture of the manner in which continents were assembled by the movement of tectonic plates that make up the crust of the Earth. A particularly interesting discovery was the detection of remnant magnetization in the Kursk Anomaly, USSR. Previously, it was believed that only the present-day magnetic field of the Earth could be detected from space.

The Landsat Thematic Mapper program, established to promote the scientific use of sensors, led to some spectacular discoveries. Volcanic eruptions, most notably in the South American Andes mountains, have produced massive volcanic landslides that were 10 to 15 times larger than the Mount St. Helens lateral-blast deposits that occurred in the State of Washington in 1980. Analysis of this phenomena clearly shows that the Mount St. Helens style of eruption is much more common than was previously believed. In fact, this information resulted in a reassessment of unusual deposits around Mount Lassen in northern California. In addition, some Andean volcanoes are not as inactive as believed. Measurements made by Landsat's Thematic Mapper show that the temperature of some lakes in the summit craters of the volcanoes are as much as 13 degrees centigrade warmer than they should be. This indicates that mild warming by heat generated internally is occurring, and may mark the beginning of more vigorous activity.

A new technique for using polarized radar signals to conduct detailed studies of different landforms has been perfected. By using the variable echo strength at different angles of polarization in a single radar image, scientists can construct a matrix that compares the radar data to theoretical models of surface reflectivity. This determines such attributes as surface roughness (at a scale of centimeters to decameters), electrical properties of soils and rocks, and physical characteristics of a tree canopy. The technique is likely to have many applications, not only in geology, but also in fields such as ecology and hydrology. A single polarized radar image can be manipulated by the scientist so that the maximum degree of contrast between two targets of interest can be obtained, a process that allows comparison of the different properties of the two surfaces.

Microgravity Science and Applications

The Microgravity Science and Applications program conducts research into the effects of reduced gravity on basic physical phenomena and processes. The program is structured into six primary scientific disciplines: combustion, metals and alloys, electronic materials, glasses and ceramics, biotechnology, and fluid dynamics and transport phenomena. The goal of the program is to quantify the effects imposed by gravity on physical phenomena and processes and, subsequently, to apply results obtained to specific ground- and space-based processes and products. Advances in research and analysis have expanded to 70 the number of high-quality ground-based investigations that are funded. Also, there are a large number of high-quality proposals that have been submitted in the six discipline areas; however, new research efforts in the Microgravity program will require growth in program resources.

Space-Based Research. During Space Shuttle flight 61-C, in January 1986, experiments were conducted in the areas of metals and alloys, biotechnology, and fluid dynamics and transport phenomena. Three of the experiments were flown aboard the Materials Science Laboratory, a cargo bay carrier, and two were performed middeck. Results of these experiments are under evaluation, and will be published in the appropriate scientific journals.

Development of new experimental apparatus to perform reduced gravity scientific research in space continued. Among the areas that the new apparatus will support are experiments in physics and chemistry; combustion science; metals and alloys; and, electronic materials. However, the Challenger accident has necessitated a complete reassessment of flight activity for the microgravity program. One consequence of the Challenger accident is the reduction of flight opportunities for microgravity science. This adversely affects development of the reduced gravity scientific data base that is required by the scientific and commercial communities to prepare for future activity aboard the Space Station.

Information Systems

The Information Systems Office (ISO) manages a data systems program to serve the data management and information processing needs of the Office of Space Science and Applications. In 1986, ISO's computer networks allowed real time science analysis during Voyager 2's encounter with Uranus, and its advanced processing systems and data bases supported modeling and analyses for the oceans, planetary, and climate programs.

ISO programs complement the data systems capabilities developed by OSSA flight projects. Systems and technologies developed by ISO are transferred to the host discipline programs for subsequent operational use, becoming part of the data systems in new flight projects. In general, through improved access to and use and management of space-acquired data, the ISO organization provides the technologies, tools, and techniques that are essential for productive scientific research.

Spacelab Flight Program

Following the Challenger accident, there was a reassessment of the Spacelab Flight program. This was required in order to maximize limited opportunities to accommodate the payloads that were previously manifested on the Shuttle. Many outstanding investigations, representing a wide variety of institutions and organizations that are at critical stages of their evolution, will experience launch delays of 3 to 5 years.

The Astronomical Observations payload (ASTRO) was completely integrated and ready for a 1986 flight. However, due to changes in the manifest, it must now wait for a 1991 launch. ASTRO's three independent ultraviolet telescopes that operate on the Instrument Pointing System (IPS) will conduct independent but complementary measurements of ultraviolet data.

Science and applications payloads planned for early Spacelab flights include the Materials Science Laboratory, International Microgravity Laboratory, Space Life Sciences, and Atmospheric Laboratory for Applications and Science. Work that will continue over the next several years is geared toward preserving a limited number of Spacelab missions. Detailed analysis of data from the three flights of Spacelab in 1985 began to emerge in technical and scientific media.

Negotiations continued with Japan over a reimbursable Spacelab Shuttle Flight (Spacelab-J). Using original launch schedules, Japan is proceeding with development of the hardware; and the science working groups, consisting of participants from Japan and the U.S., are proceeding with hopes of an earlier flight date.

Space Station

The Office of Space Science and Applications (OSSA) plans to be a major user of the resources offered by both the space and ground elements of the Space Station program. The Office visualizes the Space Station as a NASA institutional laboratory in space that will work with established ground laboratories, such as the Goddard Space Flight Center and the Jet Propulsion Laboratory. In 1986, a Space Station integration function was established to help consolidate OSSA plans and provide technical support for the conduct and management of multi-discipline studies related to use of the Station. A Science Operations Task Team was established to develop a science operations concept and plan. Use of the Space Station will allow researchers to conduct experiments in space from their own laboratories through a capability called "telescience," a concept developed by the advisory Task Force on Scientific Use of the Space Station (TFSUSS).

During 1986, important technical studies that were undertaken include defining sources of contamination that arise from or

affect the operation of scientific payloads on the Space Station; cataloging potential waste products, and providing alternatives for their management and disposal; using the pressurized volume effectively on the Space Station; and defining an approach to logistics and resupply concepts. Conducting these studies helps to define parameters of payloads and experiments, and to understand how they will be affected by the Space Station environment. In addition, Congress urged that the Space Station program be organized as early as possible to provide useful scientific research during the flight operations phase. The focus will be on identifying how the experimental facilities will be equipped, so that useful scientific research can be conducted before completion of the entire assembly sequence.

Space Transportation

Customer Services

On January 12, 1986, flight 61-C was launched on Space Shuttle Columbia carrying a communications satellite (RCA Satcom KU-1), a Materials Science Laboratory, and several small experiments. It was the last flight before the ill-fated 51-L Challenger mission.

Subsequently, most of the year's activity centered around analysis of Challenger's accident, the Space Transportation System (STS) program, and a return to flight status. After a thorough analysis of the entire STS program, a reduced flight rate was established, particularly for the years immediately following resumption of Shuttle operations. Based on the revised flight rate, a new manifest was published, and several major changes were incorporated into it. One of the most significant was the President's new policy on the commercialization of space in which he announced that NASA would no longer launch commercial satellites, except for those that are unique to the Shuttle or have national security or foreign policy implications. With NASA no longer competing in the business of launching commercial satellites, the new policy allows private industry to play an increasingly important role in space. At the time of Challenger's accident, NASA had 44 commercial and foreign launch

commitments. The President's Economic Policy Council selected 20 payloads that met the criteria for flight, and they were reflected in the published manifest.

In addition to the President's new commercial policy, a change in priorities for flying on the Shuttle was instituted in the following order: national security payloads, major scientific and interplanetary payloads, and other science and foreign and commercial payloads.

Launch and Landing Operations

In January 1986, two Shuttle vehicles were processed and launched. The first was the seventh Columbia mission, which was also the 24th successful Shuttle mission. The second launched the tenth Challenger mission that, unfortunately, led to the tragic accident, and loss of the spacecraft and her crew. Subsequently, launch and landing operations supported the accident investigation with salvage operations, vehicle assembly and disassembly activities, and facilities and processing evaluations. Additional effort was devoted to reevaluating, improving, and recertifying Shuttle processing facilities and procedures. This effort included additional assembly and disassembly of solid rocket boosters, and moving a complete Shuttle vehicle to Launch Pad B for revalidations. The Launch Pad B and the Payload Hazardous Servicing Facility were completed in 1986. Construction of an Orbiter Maintenance and Refurbishment Facility, and a Thermal Protection System Facility should be completed early in 1987.

Flight Operations

The Space Transportation System's flight operations include mission planning and control, crew training, and flight software production. As a result of the accident, a substantial effort to audit critical items is underway to assure that there are no latent flight safety problems. The hiatus in flight activities has allowed changes to be made in operations hardware and software. A significant number of these changes is now judged to be mandatory for the next flight. In addition, proficiency training of crews and flight controllers is continuing.

Improvements to operations facilities at the Johnson Space Center continued, with emphasis placed on the Shuttle Mission Simulator and the Mission Control Center. Replacement of old data processors in the Mission Control Center was completed with the installation of four IBM 3083 computers. This relieves a serious limit on capacity, is expected to lower maintenance expense, and significantly reduces unscheduled downtime. In the aftermath of the accident, plans to upgrade the Shuttle Mission Simulator were revised and accelerated. Due to capacity limitations, mandatory critical systems changes cannot be accommodated on the present mainframes. Accordingly, immediate procurement requests were made for higher capacity machines.

The Space Transportation System operations contract at Johnson Space Center completed its transition to consolidation of 22 support contracts involving 16 firms. Due to the flight operations changes resulting from Challenger's accident, renegotiation of the contract is underway.

Orbiter

During 1986, concentration of effort was on returning the orbiter to flight status. A total Systems Design Review (SDR) of the orbiter was conducted, and resulted in the identification of a number of design modifications to enhance safety. The SDR activities will continue in 1987. In addition, crew escape studies, hazard analyses, and critical items list reviews were conducted to improve safety margins. Near-term and long-term crew escape systems are being studied. For the near-term, approval has been given to provide for crew bailout through the orbiter side hatch during controlled gliding flight. The decision on which flight to incorporate such a system is pending. Previous initiatives to improve the general purpose computer, inertial measuring unit, auxiliary power unit, fuel cells, and brakes are continuing.

Approval was granted to procure a replacement orbiter. Production of this vehicle will begin in August 1987, with activity in late 1986 limited to retaining approximately 15 critical subcontractors and initiation of production planning. Delivery of the vehicle is expected in 1991.

External Tank

The external tank flown on flight 61-C performed as expected. Seven tanks were manufactured and delivered on or ahead of schedule. However, as a result of Challenger's accident, production requirements were reduced significantly and resulted in a major reduction-in-force of contractor personnel at the Michoud Assembly Facility. Also, The 5th Production Buy Contract, negotiated in late 1985, was held in abeyance, and is expected to be settled in 1987.

Solid Rocket Booster (SRB)

On flight 61-C the SRB's performed satisfactorily. As a result of Challenger's failure, production of boosters and motors stopped, and agency and contractor efforts concentrated on the failure investigation and recovery actions necessary to redesign and recertify the boosters. A complete reassessment of the program was initiated, including recertification of all SRB hardware, and reassessment of the Failure Mode and Effects Analysis and Critical Items List. Redesign of the critical seals on the Solid Rocket Motor was initiated; a baseline design, and return to flight program schedule was established; construction of the SRB Assembly and Refurbishment Facility was completed; and installation of support equipment was initiated.

Since the Air Force decided that the first Space Shuttle will not be launched before 1992 from Vandenberg Air Force Base, the Filament Wound Case (FWC) production program was "mothballed." However, in order to resume production effectively when required, the FWC development program will be completed.

Also, a thorough investigation and evaluation of other possible suppliers and alternate Solid Rocket Motor design concepts were undertaken.

Space Shuttle Main Engine (SSME)

A program was initiated to address key problem areas of the SSME that were identified following Challenger's accident, along with coincidental findings of new critical turbine blade cracks and marginal turbopump bearing temperature. These issues will be re-

solved prior to the resumption of flight in early 1988.

Improvements at the SSME manufacturer's plant were significant. Robotic welding process development was accomplished on 22 welds; and the turbopump Fabrication/Overhaul Center that will streamline and improve turbopump supply, and the engine overhaul facility were fully activated.

The alternate source for high pressure turbopumps was selected. The pumps will be designed for greater reliability, safety margin, lower operational costs, and potential incorporation into the flight program in the early 1990's.

The Technology Test Bed program was initiated, and will provide an independent means to evaluate technical advances arising from the development program, work on alternate pumps, and the technology program of the Office of Aeronautics and Space Technology.

Upper Stages

Following Challenger's accident, an extensive safety assessment of the cryogen-fueled STS/Centaur G prime upper stage was conducted that identified numerous modifications to enhance its safety; however, it was concluded that even with these changes, the degree of safety necessary for Shuttle flight could not be assured. Therefore, the Centaur G prime upper stage program was terminated. The Centaur G prime stages for the Galileo and Ulysses spacecraft were returned to the contractor plants for storage. The design of the Centaur G prime is expected to be used as one of the upper stages for the Defense Department's Titan IV launch vehicle.

Aboard flight 51-L was an Inertial Upper Stage (IUS), and a Tracking and Data Relay Satellite (TDRS). Developed by the Air Force, the IUS is used to boost TDRS spacecraft into geosynchronous orbit, and to boost spacecraft into planetary trajectories. In lieu of the STS/Centaur, the IUS was selected in late 1986 as the upper stage for the Magellan, Galileo, and Ulysses planetary missions. Due to mission requirements, the Ulysses mission will require a modified Payload Assist Module (PAM) in addition to the IUS.

Commercially developed upper stages play a significant role in the Nation's space activities. Since 1980, the PAM-D and PAM-DII Payload Assist Modules, developed by McDonnell Douglas, performed successfully on



Artist's depiction of the Transfer Orbit Stage, the upper stage that will be used for the Mars Observer planetary mission.

38 missions launched by expendable launch vehicles and the Shuttle. Orbital Sciences Corporation is developing two upper stages. One, the Transfer Orbit Stage (TOS), will have greater capability than the PAM stages and, in 1986, was selected by a Source Selection Board as the upper stage for the Mars Observer planetary mission. The other is the Apogee Maneuvering Stage, whose capability, when used as a second stage with TOS, will exceed that of the IUS.

Orbital Maneuvering Vehicle

In 1986, TRW was selected as the prime contractor for the Orbital Maneuvering Vehicle (OMV). The OMV will perform payload delivery to and retrieval from the Shuttle orbiter. It will be available for flight late in



Attachment points of the Orbital Maneuvering Vehicle that will perform payload delivery to and retrieval from the Space Shuttle.

1991, and its first primary mission is expected to be an orbital reboost of the Hubble Space Telescope. A second OMV may be acquired for the Space Station.

Tethered Satellite System

The Tethered Satellite System is a cooperative development between NASA and Italy to provide a capability for conducting experiments in the upper atmosphere and ionosphere. It will be capable of deploying and retrieving a tethered satellite up to 100 kilometers below or above the Space Shuttle which will serve as the orbiting base.

In 1986, Critical Design and Manufacturing Reviews were conducted on the satellite and the deployer, supplied by Italy and NASA, respectively. Deployable boom qualification was nearly completed, and delivery of the tether is expected in January 1987. In late 1986, science investigations were initiated for the first mission, scheduled for October 1990.

Spacelab

In 1985, there were three successful flights using the module and igloo pallets. After Challenger's accident, Spacelab 2's flight hardware, consisting of the igloo, three pallets, and the Instrument Pointing System (IPS), was disassembled and placed in storage awaiting resumption of Space Shuttle operations. The design for operating the Spacelab Igloo Pallet configuration's mixed cargo mode, to support the Astro 1 mission, was completed and reviewed. In this configuration, using an igloo, two pallets, and the IPS, the Spacelab is scheduled to fly in January 1989. Development of the configuration for the Spacelab Enhanced Pallet continued; it will be used for missions of the Space Technology Experiment Platform and Tethered Satellite System.

The development of Goddard Space Flight Center's "Hitchhiker" was completed. The first Hitchhiker, a Shuttle Payload of Opportunity carrier, was flown on flight 61-C. Also, this flight carried a Materials Science Laboratory using the Multi-Purpose Experiment Support Structure provided by the Spacelab. The new Payload Operations Control Center was completed at Marshall Space Flight Center, and preparations are underway for it to support the Astro 1 mission.

An agreement was negotiated with the Strategic Defense Initiative Office to provide integration, operations, training, and associated launch support for a Spacelab mission scheduled for 1989. In June, the Spacelab program initiated the Spacelab Recertification program as part of the efforts to resume flight operations.

Expendable Launch Vehicles (ELV)

NASA's ELV's were used to fulfill commitments to launch space application missions for the National Oceanic and Atmospheric Administration, and the Department of Defense. In 1986, a total of five launches was conducted, consisting of a Scout, an Atlas/Centaur, an Atlas-E/F, and two Delta vehicles. One of the Delta vehicles failed during launch and was destroyed before boosting a NOAA/GOES-G satellite into transfer orbit. An investigation concluded that the failure was caused by an electrical short in the vehicle wiring. Wiring modifications were incorporated into all remaining Delta vehicles; in September, a Delta vehicle successfully launched a DOD mission.

As a result of the Challenger tragedy, NASA initiated studies on the need to establish a Mixed Fleet Transportation System consisting of the Space Shuttle and existing or new ELV's. The studies should be completed early in 1987.

Advanced Planning

Under a White House directive to define technology that would substantially lower the costs of launch capability in the post-1995 period, examination of future launch vehicles is continuing. To fulfill these objectives, NASA and DOD are managing contracts to study systems architecture. Concurrently, studies were initiated by NASA in areas of key technology, such as those related to developing new rocket engines and advanced recovery systems, and defining a second-generation Shuttle with advanced technology.

The National Commission on Space outlined a program and goals for the U.S. civilian space program for the next few decades.

Initial studies were completed of a space-based Orbital Transfer Vehicle with an aerobrake that cuts propellant requirements in

half. An aerobrake flight experiment was defined as a possible new start in 1988.

Development continues on a series of flight demonstrations that include a plasma motor/generator, an internal Shuttle communications system, using infrared light waves to replace wiring, a laser docking sensor to improve efficiency of the Shuttle during rendezvous and docking with a target, and a voice command system to control equipment and reduce current hands-on requirements. A flight unit of the standard hydrazine fluid coupling was delivered to TRW for use on the Gamma Ray Observatory. The coupling will be installed in the spacecraft during assembly to allow on-orbit servicing after launch.

Three parallel Phase B studies have been completed on a tanker to refuel satellites on-orbit. Planning will proceed in 1987 for the possible development of an operational tanker to support refueling the Gamma Ray Observatory.

The problem of orbital debris resulting from man-made structures and operations in space continued to be examined, from both technical and policy standpoints, by an Orbital Debris Working Group. The group continued to examine options for ground- and space-based tests and observations, NASA policy implementation, and provided technical support for the development of national and international debris policies.

A study and laboratory program to define and evaluate several highly promising applications of tethers in space continued in 1986. The focus of these efforts has been directed toward defining and implementing flight experiments and demonstrations. Applications being investigated include power generation, orbital altitude changes without the use of propellants, artificial gravity, and space platforms.

Commercial Use of Space

The focal point for NASA's program to encourage commercial space activities is the Office of Commercial Programs (OCP). The major objectives of OCP are to encourage U.S. private sector involvement and investment in commercial space ventures, and to facilitate commercial application and transfer of existing aeronautics and space technology to the private sector.

Centers for the Commercial Development of Space

In 1986, OCP established and funded four additional Centers for the Commercial Development of Space (CCDS), for a current total of nine. As an alliance of industry, academia, and government, the CCDS's will use the space environment to stimulate high technology research that may lead to the development of new products and services with commercial potential. If certain performance criteria are met, the Centers will be funded up to five years, after which each Center will be self-supporting.

Federal Research Facilities

In 1986, OCP began designing and fabricating space experimentation hardware, facilities, and programs to assist private sector commercial researchers in the area of materials processing. They include an advanced automated directional solidification furnace, a multiple experiment processing facility, a chemical vapor deposition facility, an organic protein crystal growth system, and a sounding rocket flight program. When completed, they will be available, at no charge to U.S. industry, to support space-related research and development programs.

More than 30 agreements have been executed with U.S. firms interested in conducting space-related research and development in the areas of pharmaceuticals, semiconductor electronic materials, metals and alloys, and organic polymers. Under additional agreements, U.S. firms will develop, with private funds, a man-tended industrial space facility, available for lease or purchase, and an interactive radio determination satellite system that will provide real time, satellite-based position information and digital message service.

Technology Utilization Program

Cooperation with industry is the cornerstone of a successful technology transfer program. Over the years, NASA's Technology Utilization program created an extraordinary base of cooperation with broad sectors of U.S. industry. It accomplished this through its nationwide network of Industrial Applications Centers (IAC's), the dissemination of

publications and computer software, conferences and seminars on the subject of technology transfer, and technology applications projects. In 1986, NASA continued these efforts, strengthening the outreach activities to develop increased industrial interest and participation in the commercial uses of space. In addition, the non-aerospace industrial community will have more opportunity to participate in activities with NASA in the areas of technology transfer, and the commercial uses of space.

The successful privatization of *NASA Tech Briefs*, the agency's primary publication on technology transfer, has enhanced and supported NASA's interaction with industry. By the end of 1986, the number of industrial and business subscribers exceeded 130,000, reflecting a 70 percent increase over the previous two years. Other signs of continued expansion are the linkages that were established between the NASA IAC's and state-funded organizations involved in industrial and economic growth. Currently, the IAC's have formal relationships established with industries in nearly 20 states that provide computerized information access to NASA, and other technical data bases. These efforts have created a nationwide technology transfer network, allowing U.S. industry direct access to useful technology through scientific and technical information. In addition, under the Federal Technology Transfer Act of 1986, NASA entered into an agreement with the Federal Laboratory Consortium that links IAC's with federal laboratories, and their personnel, engaged in research and development activities that may have specific application to private sector needs.

In 1986, an experimental program in technology transfer was initiated at NASA's Jet Propulsion Laboratory (JPL). Administered by the Research Institute for the Management of Technology, this program allows companies to use JPL's extensive technical resources and, thereby, accelerate the transfer of NASA developed technology to the commercial sector. Currently, eight companies in Southern California are active in the program; a total of 20 are expected to participate by the summer of 1987.

In an attempt to solve industrial and public sector problems of national significance, NASA, other federal agencies, and the private sector use existing aerospace technology. In 1986, several prototypes from biomedical applications projects were completed, and are



Based on technology developed for space systems, the Programmable Implantable Medication System will be used to deliver precise doses of medication to control diabetes and other diseases.

undergoing clinical evaluation. They include a Programmable Implantable Medication System, a burn diagnostic system, and a bladder dystension system for the handicapped. In addition, NASA entered into a joint project with the Veterans' Administration, the National Institutes of Health's National Institute of Aging, and the Administration on Aging to develop a device to alleviate the problems of wandering in the elderly. Also, this group has initiated an applications project to help the elderly with low vision problems. Currently, NASA and the U.S. steel industry are exploring the use of aerospace technology to resolve problems of abrasion and material fatigue associated with the steel casting process.

Small Business Innovation Research

During 1986, OCP continued to manage NASA's Small Business Innovation Research (SBIR) Program. The program's objective is to achieve greater participation by small, innovative businesses in NASA's research and development activities, providing mutual benefits to the agency and small businesses, and to the Nation's economy as a whole. As specified by law, program funding for the year was 1.25 percent of NASA's extramural research and development budget. The year's annual program solicitation was open between May 1 and June 30. It yielded 1,628 research proposals from which 172 were selected for award of Phase I SBIR contracts.

Phase I SBIR contracts are intended to explore the feasibility of research innovations,

and are awarded for 6-month periods, averaging approximately \$50,000 each. Phase II SBIR contracts continue development of the most promising Phase I projects, lasting as long as two years, with funding to \$500,000 each. During 1986, 71 Phase II contracts were let for selections that were made in late 1985 as extensions of Phase I contracts. At the end of 1986, 49 additional Phase II projects were selected to continue promising Phase I contracts that were completed in 1986. It is anticipated that early in 1987, 30 additional proposals will be selected for Phase II awards.

As in the past, the year's SBIR Program solicitation and awards included every area of research and technology in which NASA is involved. However, the proposals that were received reflected increased interest in potential commercial uses of space. Fifty-five of the research proposals for Phase I contracts involved materials processing in microgravity, and commercial applications of space; eight of the proposals were selected for Phase I awards.

Space Station

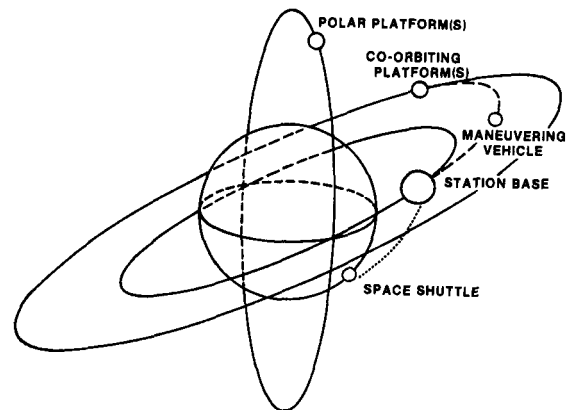
During 1986, NASA's efforts continued on the Space Station program. The agency's goal is to fulfill President Reagan's 1984 directive to establish a permanently manned presence in space in the mid-1990's. Most of the work on the definition and preliminary design portion of the schedule was completed. Changes were made to the assembly sequence and management structure; technical and management issues were identified and resolved; and U.S. Government and NASA's negotiators made progress on agreements for hardware development with its international partners: the European Space Agency, Canada, and Japan. At the end of 1986, NASA was developing for industry a Request for Proposals to design and build the Space Station.

Program Goals and System Description

The Space Station is unlike any previous NASA undertaking. As a multi-purpose facility, it will satisfy the goals of many users. The program's goals are to:

- assure free world leadership in space during the 1990's and beyond
- stimulate technological advances
- promote international cooperation
- enhance capabilities for space science and applications
- develop the commercial potential of space
- contribute to American pride and prestige
- stimulate interest in science and engineering education

The Space Station will consist of a manned base, with pressurized modules, and an integrating truss structure, inclined at 28.5 degrees. The base will consist of a servicing structure, habitat, logistics and laboratory



Initial Space Station Complex.

modules; berthing and assembly fixtures; power generating solar arrays; and an advanced mobile remote manipulator system. For near polar orbits, two or more platforms will be developed and serviced by the Space Shuttle; and all elements will be ferried to orbit by this spacecraft.

Adhering to some of NASA's earlier architectural concepts, the Space Station will be an orbiting scientific laboratory, and a permanent observatory in space. The facility could be used to process materials, manufacture commercial products, and service satellites; and, with enhancements, could assemble large spacecraft; stage deep-space missions; and service and deploy satellites and upper stage rockets.

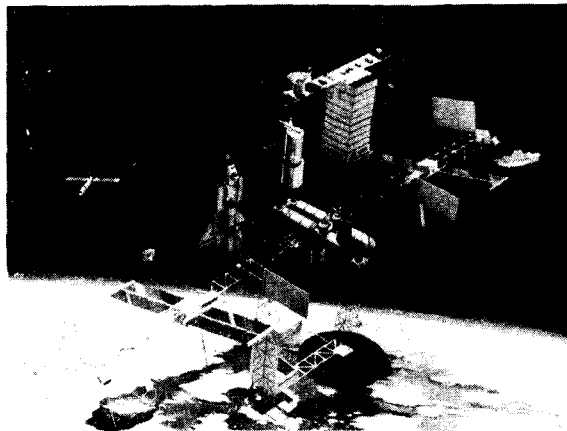
Above all, the Space Station is planned as an evolutionary facility that will allow growth and technological innovations. Although it is difficult to incorporate specific design provisions for all potential endeavors,

Space Station planners will consider carefully the implications of evolutionary changes in their design of the Space Station complex.

The Space Station is a civil program, and the Department of Defense (DOD) has not as yet identified any requirements. However, the United States reserves its option to use the U.S. provided elements and Space Station infrastructure for peaceful purposes, consistent with international obligations.

Program Status

In 1986, the most significant event in the Space Station program was the selection of a

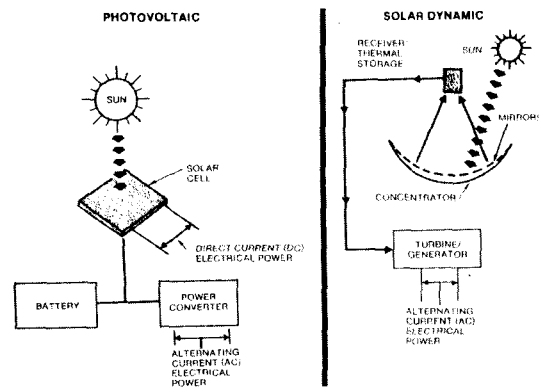


Space Station "dual keel" configuration.

baseline configuration for detailed design and development activities. Six contractors at four NASA "work package" Centers were involved, and studies on possible hardware contributions were conducted by NASA's international partners.

Through trade studies and analyses, NASA and industry teams examined the merits of various design options. As a result of the System Requirements Review, a recommended baseline configuration for the Space Station emerged. The original "power tower" concept evolved into the "dual keel" configuration. In addition, a hybrid power-generation arrangement was defined, consisting of both photovoltaic and solar dynamic components; 400 kilometers was chosen as the operating orbital altitude; and an assembly sequence was selected.

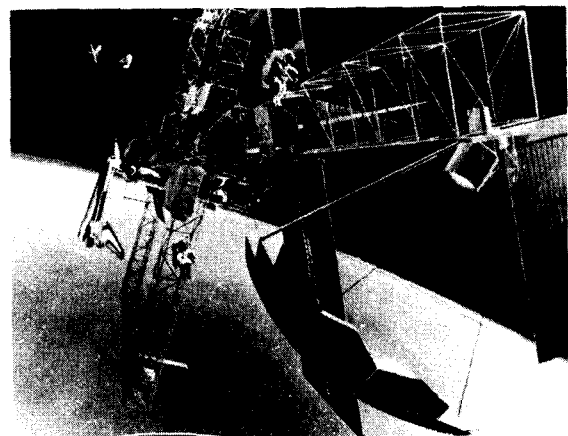
User requirements were a prime consideration in defining capabilities and designing the Space Station. The objective remains to



Space Station Program Solar Power Options.

create a facility that is user friendly. Potential users from the scientific and commercial communities continued to update their contributions to the Mission Requirements Data Base (MRDB). In 1986, over 300 proposed missions of various sizes were identified and included in the data base. Each entry describes the mission and its objective, physical characteristics of equipment, and requirements of Space Station resources such as power, thermal dissipation, crew assistance, and data handling. There can be as many as 200 parameters to define a particular mission. The information provided in the MRDB was used to evaluate potential designs of the Space Station and associated platforms. In 1986, the reliability of the data base increased significantly.

Because the dual keel baseline design involved a large number of technical and programmatic considerations, Space Station



Artist's rendition of Space Station Solar Dynamic System in lower right.

contractors, international partners, and potential users assisted NASA's Critical Evaluation Task Force (CETF) in conducting a

comprehensive review of the dual keel design. Also, options and assembly scenarios were identified that addressed the issues of transportation capability, constraints on extravehicular activity (EVA), resource allocation, safety, and cost. In September, the CETF's recommendations were presented to the Administrator, and further analyses were requested. By year's end, the studies were completed; the CETF configuration reflected key changes to the assembly sequence, subsystem hardware locations, and expanded use of resource nodes.

A revised flight sequence was adopted to accompany CETF's recommendations. A total of 32 Space Shuttle flights were identified to assemble, service, and resupply all elements of the Space Station. The facility will attain a man-tended capability in six flights, and will meet the target for a permanently manned station by flight eleven.

During the last four months of 1986, a Space Station Cost Commitment Review (CCR) was undertaken to establish a detailed cost estimate as the program evolves from the definition and preliminary design phase to actual design and development. Emphasis was placed upon obtaining more accurate development costs for flight hardware and software. To this end, CETF's recommendations were converted into guidelines for work required at each of the work package centers. A final report is expected in early 1987 that will contain a revised program, and associated costs and schedule.

Progress was made in laying the groundwork for U.S. industry to benefit from space in the future. The internal Commercial Advocacy Group conducted workshops to identify and encourage potential commercial users of the Space Station. The Group supported activities to foster private sector interest in using the Space Station for materials processing, Earth and ocean remote sensing, communications satellite delivery, and industrial services. In August 1986, "Guidelines for United States Commercial Enterprises for Space Station Development and Operations" were established. They are intended to encourage U.S. private sector investment and involvement in the development and operations of Space Station systems and services.

Advanced Development Programs played a major role in decisions to incorporate new technologies into the Space Station preliminary design. In October and November of 1986, a review was made of Advanced Development

Programs that focused on high-leverage technologies for specific Space Station applications. Evaluation and testing were conducted in areas such as attitude control and stabilization, data management, communication and tracking, environmental control and life support systems, extravehicular activity, fluids, manned systems, materials, mechanisms, power, propulsion, structures, and thermal control. The aim is to develop these technologies so that they can be tested on the ground or in the Space Shuttle.

An Operations Management Concept was formulated that outlines the philosophy and management approaches to Space Station operations. Using the Concept as a point of departure, an Operations Task Force was established to perform a functional analysis of future Space Station operations. Expected in early 1987, the Task Force report will provide an operations concept that examines all functions, and integrates them into requirements for implementation. The Task Force will provide a separate document offering design and development recommendations for Space Station hardware contracts.

The Space Station Information System (SSIS) will allow the acquisition, transmission, recording, processing, accounting, and storage of information generated by orbital and ground systems. In 1986, an architecture definition was developed for the total integrated system. The Technical Management and Information System (TMIS) is part of the SSIS that will support the flow of technical and program management information; in July, the Request for Proposals (RFP) for the TMIS was released. Responses from industry were received in October, and a contract award is expected early in 1987. The Software Support Environment (SSE) is the software, training materials, and other required documentation that will provide the "environment" for the life cycle management of all program software. Responses to the RFP's for the SSE were received in November, and are currently under review.

Oversight Activity

Planning for the Space Station involved a number of scientific advisory groups such as the Task Force on Scientific Uses of the Space Station (TFSUSS), created under the auspices of the NASA Advisory Council. Chaired

by Dr. Peter Banks of the Space, Telecommunications and Radioscience Laboratory at Stanford University, TFSUSS consists of 20 U.S. scientists and several international observers. The TFSUSS recommended that the Station's manned base and platforms provide important new capabilities for the conduct of scientific research in space. In 1986, NASA reported to Congress on the TFSUSS recommendations that it intends to implement.

At the request of Congress, NASA prepared a technical study of an approach that phases in the permanently manned features of the Space Station. Completed in May 1986, the study demonstrated that a man-tended Station, one visited occasionally by astronauts, could be developed and would provide some useful capabilities. There would be a single, multi-purpose laboratory module equipped with a partial environmental control system.



Artist's conception of Space Station crew at work in a pressurized module.

The power capability of 37.5 kilowatts would be one-half the power planned for the final configuration, and consist of solar cells only. A cost analysis revealed that a cost deferral, by delaying fabrication of facilities that would allow continuous crew presence, would be offset by both the cost of operating the Station in the man-tended mode and maintaining the industrial base during the delay period. The man-tended mode remains a viable option in the drive to achieve a fully productive and useful manned Space Station.

To ensure that the Space Station program fosters automation and robotics technologies in the United States, Congress requested the formation of an Advanced Technology Advisory Committee (ATAC). In response to ATAC's recommendations, NASA continued to refine its "Automation and Robotics Imple-

mentation Plan for the Space Station Definition and Preliminary Design Phase." The goal is to facilitate the integration and use of future automation and robotics technologies as the Space Station evolves. Principal areas of interest for automation and robotics include: system management and crew activity; data base management; power system control and management; monitoring and fault detection for life support systems; Space Station assembly, inspection and repair; and payload servicing and docking. The Flight Telerobotic Servicer Program (FTS) was mandated by Congress, and is a direct outgrowth of the automation and robotics initiative. The FTS is a highly automated telerobotic device, capable of precise manipulations in space, that will be used with the Mobile Servicing Center and the Orbital Maneuvering Vehicle to assist in assembly and servicing operations. Late in 1986, a preliminary program plan for the FTS was submitted to Congress.

In 1986, a Space Station Engineering and Operations Safety Oversight Panel was established that examined the implications of the Challenger accident for the Space Station program. It addressed the question of whether the Space Station requires a Crew Emergency Return Vehicle. The issue is still under review.

Program Management

In order to distribute work more equitably, enhance accountability, and capitalize upon the expertise available at NASA's Centers, it became appropriate to alter the Space Station's management structure.

In May 1986, NASA enlisted the aid of former Apollo Program Manager, General Samuel Phillips, to review the program's management structure. His goal was to recommend a management structure that would secure accountability, efficiency and economy in the design, development, test, and integration of the Space Station. He formed a committee of experienced managers from the aerospace industry to assist him. Among the Committee recommendations were the establishment of a Program Management Office at NASA Headquarters, headed by a Program Director, and supported by a contractor with expertise in system engineering and analysis; and line direction from the Headquarters Program Office to Center project managers.

Based upon the Phillips recommendations, NASA's senior management delegated responsibilities for development to: Marshall Space Flight Center—laboratory module, habitation module, logistics module, and resource node structure; Johnson Space Center—external truss, distributed subsystems, EVA systems, airlock and node outfitting; Goddard Space Flight Center—platforms, attached payloads, and Flight Telerobotic Servicer; and Lewis Research Center—power system.

The Space Station program stayed on schedule during the definition phase. The varied challenges to the technical configuration, and to the program's management structure were met. The result is a preliminary design, and an organizational structure better able to satisfy the needs of Space Station users, and a program that will be the focus of NASA planning activities for many years to come.

International Cooperation

Significant progress has been made since the Spring of 1985, when Memoranda of Understanding for Phase B cooperation were signed between NASA and the space agencies of Canada, Europe, and Japan.

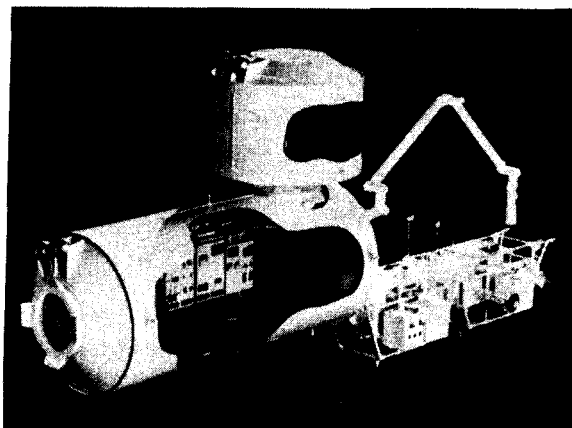
Canada proceeded with the definition and design of a Mobile Servicing Center (MSC) that includes remotely controlled manipulator arms and a maintenance facility. The MSC will be used in orbit to assist in assembling and maintaining the manned base; service external payloads attached to the truss structure; and provide transportation and EVA support. NASA will provide a carrier platform for moving the servicing system to different locations on the base.

The European Space Agency (ESA) continued definition and design studies of a permanently attached pressurized laboratory module. Design efforts continued on an unmanned polar-orbiting platform for Earth observations. Jointly, ESA and NASA are studying a proposed man-tended, free-flying facility that would provide a very low gravity environment for extended periods of time.

Japan proceeded with definition and design studies of a pressurized laboratory module to conduct general science and technology research. It features both an external deck to mount experiments requiring exposure to space, and an airlock to move experiments in

and out. Also, Japan is continuing to define and design an experiment logistics module to resupply its facilities.

Bilateral negotiations began between NASA, Canada, ESA, and Japan on the programmatic/technical parameters of the program, and on legal issues, such as liability and patent law. Agreements from the negotiations are expected to commit all partners to hardware investments, operational roles, and use of the Space Station for many years.



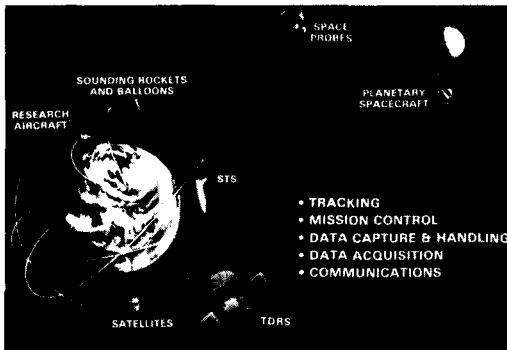
Model of Japanese Experiment Module.

Space Tracking and Data Systems

The Space Tracking and Data Systems program is responsible for planning, implementing, and operating worldwide tracking, data handling and communications facilities and services that support flight programs of NASA and other agencies. During 1986, the program continued to provide support for planetary spacecraft, Earth orbiting satellites, Shuttle missions, sounding rockets and balloons, and aeronautics test vehicles.

The Space and Ground Networks continued to provide vital tracking, command, telemetry, and data acquisition support to meet the requirements of NASA's flight programs.

Two Tracking and Data Relay Satellites (TDRS) that were scheduled for their respective launches in January and July 1986 would have completed the operational satellite constellation of three in orbit. The TDRS aboard Space Shuttle 51-L, launched on January 28, 1986, was lost. However, the two TDRS spacecraft are scheduled for launch



Tracking and Data Acquisition Functions.

when Shuttle operations resume in 1988. Ground based tracking operations that support spacecraft in low Earth orbit were extended to provide coverage until the TDRS system becomes operational.

The Deep Space Network (DSN) continued to support missions to explore the solar system. A modification of the DSN was key to the impressive success of Voyager 2's January 1986 encounter with Uranus, and its rings and moons. Also, in 1986, the DSN supported the Interagency Consultative Group (IACG) during the international observation of Halley's Comet.

The Communications and Data Systems program continued its support of NASA missions. The International Ultraviolet Explorer (IUE) telescope was restored to service after an equipment failure. In 1986, reprogramming the computer on the International Cometary Explorer (ICE) spacecraft from the control center extended the spacecraft's communications capability as it travels farther from Earth on its twenty-year orbit.

Space Network

The Space Network is comprised of the Tracking and Data Relay Satellite System (TDRSS), and NASA ground elements that include a Network Control Center, Ground Terminal, Flight Dynamics Facility, and Simulation Operations Center. Logistics, mission planning, and documentation support are provided to maintain operations.

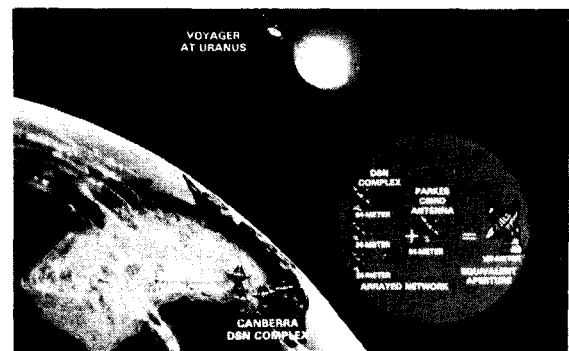
The one TDRS spacecraft operating in space continued to support Landsat, Solar Mesospheric Explorer, and Earth Radiation Budget Satellite missions. The Tracking and Data Relay Satellite System will be considered fully operational when the second

and third spacecraft are located in the east and west service positions in geosynchronous orbit. The first TDRS has been moved to the central service position as the on-orbit spare, and that spacecraft, and the ground terminal, have completed their individual and systems tests. Approximately three to four months after launch of the third spacecraft, full operational status is expected.

In 1986, the TDRSS program initiated plans for a second ground terminal, and released a Request for Proposals on competitive design studies. In the event of a catastrophic failure of the existing station, this ground terminal will provide a backup. In addition, it could provide expanded capabilities in the mid-1990's when mission requirements may exceed current TDRSS system capacities. The second terminal will be located near the first to reduce costs, and simplify operations and maintenance. Also, procurement of a spacecraft to replace the TDRS that was lost in the Challenger accident was initiated.

Ground Network

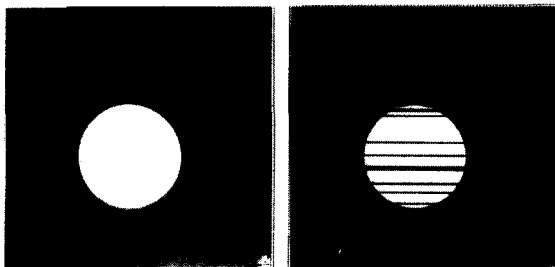
The Ground Network continued to provide tracking and data support for NASA's missions. It consists of the Spaceflight Tracking and Data Network (STDN), the Deep Space Network (DSN), and ground tracking and data acquisition facilities that support aeronautics, balloon, and sounding rocket programs. In order to provide coverage, phasing out most of the existing STDN will be delayed until the TDRSS becomes operational.



Arraying of Deep Space Network antennas in Australia to support Voyager 2's encounter with Uranus.

Its flawless support of Voyager 2's encounter with Uranus in January was the high point of the year for the Deep Space Network. This support relied on a new method of arraying large antennas, and combining NASA's

own signals with those from a large antenna in Australia. Also, during the international observations of Halley's Comet in March and April, the DSN supported Japanese efforts to track their two spacecraft; provided backup tracking of the European Space Agency's (ESA) Giotto spacecraft; and tracked the Soviet Vega spacecraft as they approached the Comet. Data from the Vega orbit, supplied by the Soviets, was used to refine the trajectory of the Comet, which allowed ESA to retarget Giotto to achieve a closer encounter. This exemplified international cooperation at its best, providing greater scientific return than would have been possible from individual efforts. In addition, the DSN supported other spacecraft that observed the Comet, namely NASA's Pioneer-Venus and International Cometary Explorer (ICE).



Arrayed and non-arrayed images of Uranus obtained by Voyager.

In 1986, efforts were underway to increase the sensitivity of the DSN in preparation for Voyager 2's encounter with Neptune in 1989. At that time, signals received on Earth will be less than one-half as strong as they were from Uranus. Improved efficiency will be accomplished by increasing the large DSN antennas from 64 to 70 meters, and, during the encounter, by simultaneously combining signals received by DSN antennas with those received by antennas at non-NASA facilities.

Communications and Data Systems

The basic elements of the Communications and Data Systems program form the vital link between data acquisition stations and users, and include communications, mission control, and data processing.

In 1986, two major projects in NASA's Communications program that became operational used advanced technologies developed by the communications industry. First, a Time Division Multiple Access (TDMA) system, provides operational circuits, via satel-

lite, that can be used by NASA's facilities, as workloads require. Second, a Program Support Communications Network (PSCN), handles the non-operational communications needs of NASA's Centers. The services provided include voice, management and administrative traffic, and technical data interchange.

In 1986, major accomplishments included operational control of nine orbiting spacecraft; the development of facilities in preparation for launches of future spacecraft that include the Hubble Space Telescope, Cosmic Background Explorer, Gamma Ray Observatory, and Upper Atmosphere Research Satellite; and plans were initiated to develop facilities for platform control, communications, and data capture for use by the Space Station.

Space Research and Technology

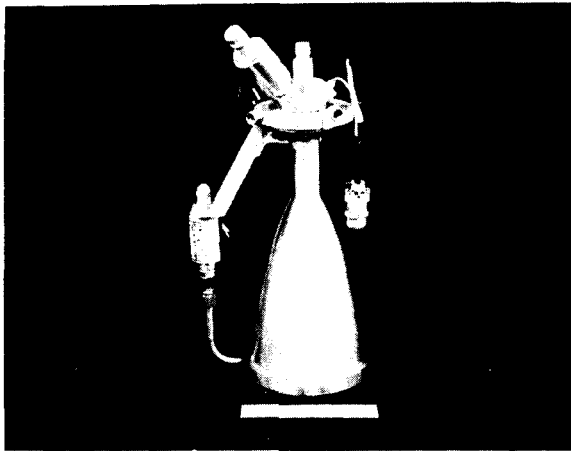
The goal of the Space Research and Technology program is to conduct effective, productive, and critical research that contributes materially to U.S. leadership and security in space. Achieving this goal requires a strong commitment to advancing the technology base; maintaining technical strength in the scientific and engineering disciplines; developing more capable, less costly space transportation systems, and large space systems with growth potential; promoting scientific and planetary exploration to improve understanding of Earth and the solar system; and supporting the commercial exploitation of space. Disciplines included in the program are propulsion, space energy conversion, aerothermodynamics, advanced materials and structures, controls and guidance, automation and robotics, space human factors, computer science, sensors, and data, communications and space flight systems. All NASA Centers are involved in the Space Research and Technology program, along with significant participation by industry and universities.

Propulsion. Research in this area has improved the technology base by contributing considerable data on all types of chemical and electrical propulsion systems. Earth-to-orbit propulsion research emphasizes high-performance and extended service life. In this critical area, a cryogenic engine bearing model was developed to determine cooling, lu-

brication, and bearing design characteristics. Another new model predicts the life of materials subjected to both low-cycle and high-cycle fatigue. Optical sensors were demonstrated for tracking bearing wear, and measuring turbine blade temperatures and rotor speed. Redesign of turbine blade materials demonstrated the potential to sustain up to 20 times the fatigue life of existing blade materials. Computational Fluid Dynamics (CFD) codes for rocket engine hot gas flows were used to optimize minimum pressure drop in flow passages. In addition, the combustion characteristics of turbine drive gas generators, operating with LOX/propane, were determined. Application of this technology to Space Shuttle Main Engines, and to other propulsion systems, is expected to improve the ability to predict the life expectancy of reusable propulsion systems.

Orbit transfer propulsion research focused on developing high-performance, high-pressure, variable-thrust engines that will be stored and fueled in space. For example, technology for space-based LOX/hydrogen expander cycle engines advanced in the areas of combustion, heat transfer, materials compatibility, high-expansion ratio nozzle performance, and engine level system testing. The test firing of an expander cycle engine verified that high-pressure operation for high-performance can be achieved.

In 1986, the technology for small chemical thrusters in low-thrust propulsion advanced

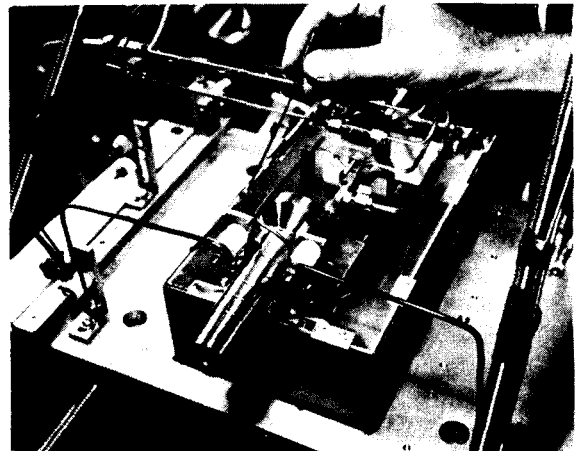


Hydrogen/oxygen thruster design for the Space Station's maneuvering system.

significantly. Successful test firings of storable bipropellants that allow higher burning efficiency and deliver 10 percent more energy are of particular significance to future planetary missions. Areas in spacecraft previously reserved for propellants can now be used for

scientific payloads. In addition, the performance during tests of hydrogen/oxygen thrusters was so impressive that they were accepted as the baseline design for the Space Station's major maneuvering system.

In electrical propulsion, advances were made from research on resistojets, arcjets, ion and magnetoplasmadynamic (MPD) thrusters. Electric propulsion devices are most useful to planetary missions requiring high-specific impulses. They are also used for satellite altitude control, orbit changing, power, and guidance and control of large structures. A new platinum-alloy resistojet heater was selected as the drag-neutralizing thruster for the Space Station, an action that is considered significant because a resistojet can operate on waste gases from the Space Station to compensate for drag forces. Small arcjets operating on less than one kilowatt of power demonstrated smooth starting and operating characteristics at performance levels

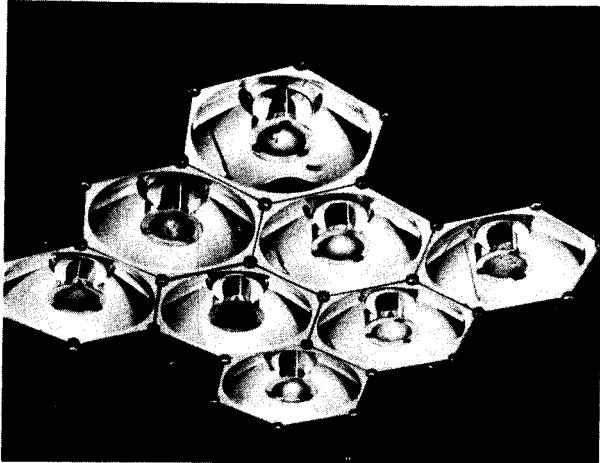


Final adjustments to a test stand before vacuum chamber testing of resistojet.

of up to 700 seconds of impulse. This assures their application to future satellite systems because existing systems develop only 300 seconds of impulse. By tripling power thrust levels, and initiating a two-thruster, computer-controlled simulated stage to investigate component interactions, ion thrusters became more acceptable. Compared to chemical systems, the MPD thruster proposed for advanced propulsion systems has the potential to provide a two to fourfold reduction in propellant mass. New testing, at low-power levels, resulted in a better understanding of MPD component life.

Space Energy Conversion. This research provides the design base for high-performance, long-life power systems for space appli-

cations that include solar power, nuclear power, batteries, and thermal systems. Progress continues to be made in improving the performance of solar photovoltaic (PV) cells and arrays; recent success in testing includes the reduction of output lost due to natural radiation. In geosynchronous orbit, a conventional silicon PV system can lose up to 25 percent of its output during a seven-year life; and in the radiation belts, the loss can be as



Photovoltaic mini-cassegrainian lenses.

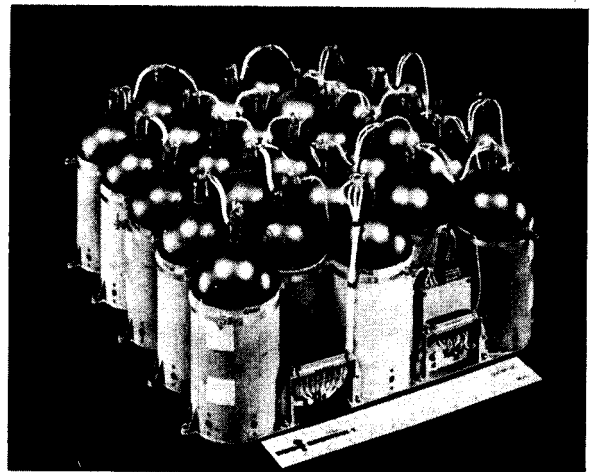
high as 80 percent. Approaches taken to improve this problem include use of a PV concentrator array, with mini-cassegrainian lenses and concentrated sunlight, to deliver 100 watts per kilogram of weight. In this case, the lenses blocked all damaging radiation. In another approach, materials such as gallium arsenide (GaAs) that are less susceptible to radiation were used; of these materials, GaAs is the best because it degrades less than half as much as silicon. In 1986, a small GaAs cell was exposed to a 100-to-1 solar concentration, resulting in the highest output ever produced by a space PV cell. A new material, indium phosphide (InP), showed promise of degrading even less than GaAs. A flight experiment with InP cells was developed and will be space-tested for radiation resistance.

In 1986, Phase II of the joint DOD/DOE/NASA Space Nuclear Reactor Power System Development Program (SP-100) began. The goal is to provide advanced technology options to achieve higher power levels, improved system efficiency, and increased reliability and lifetime, while reducing mass and volume. In the area of thermal power, validation testing of the 25-kilowatt free-piston Stirling engine, the largest of its kind in the world, was conducted. In the area of materials, tungsten fiber-reinforced niobium

matrix composites were fabricated and tested to a strength/density ratio of more than three times that of the current baseline SP-100 material. Research efforts in the areas of structures and materials can pay handsome dividends for the high-temperature, weight-critical SP-100 power system.

Advanced solar dynamic power systems for small and larger power needs of up to 300 kilowatts were explored in subscale tests in the critical technology area of concentrators such as Fresnel lenses, microsheet materials, heat receivers and related thermal energy storage materials. From the standpoint of performance, longevity, and power systems integration, use of the free-piston Stirling engine cycle looks very promising.

For the high-power and high-voltage that will be required in future space applications, tests confirmed that the bi-polar nickel hydrogen battery is an attractive alternative



Cell stack of nickel-hydrogen batteries.

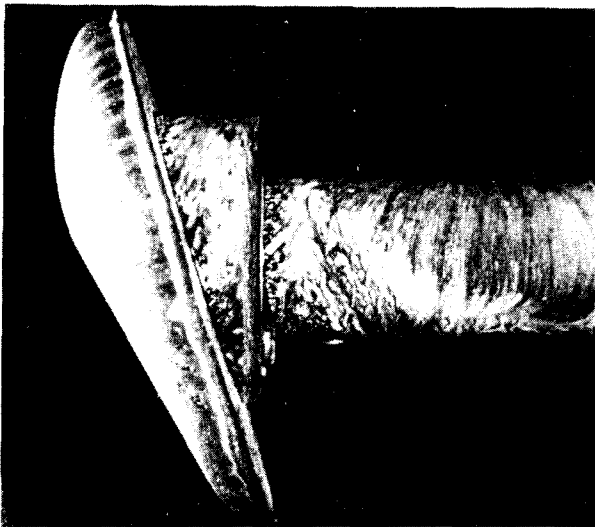
to the individual pressure vessel nickel-hydrogen battery; and results of designs tested indicated an improved weight and volume energy density of about 20 percent. Component improvements will also enhance battery life for use in low-Earth and geosynchronous orbits.

In 1986, significant progress was made in developing thermal management systems which consist of heat pipes, thermal loops, and radiators. To avoid excessive and damaging temperatures, excess heat from electric energy must be removed. High-temperature heat pipes are very efficient, although heavy and limited in use to about 700°C. New lightweight composite materials proved feasible in the fabrication of heat pipes for use at 1000°C.

Thermal loops are used to transfer heat from a point of generation to a distant radiator. A very efficient heat loop system was developed in which the circulating fluid is pumped by capillary action, eliminating mechanical pumps and increasing reliability. Key components of this system were flown on a Space Shuttle experiment in January 1986, and the system is a prime candidate for use on the Space Station.

Liquid droplet radiator components were tested in drop towers simulating near-zero gravity for about 5 seconds. The tests proved that a uniform stream of properly directed droplets could be formed. The significance of liquid droplets is that they lose heat while moving through space to a thermal collector. The cooled liquid is pumped back to the heat source and the process is repeated.

Aerothermodynamics. Research in this field improves understanding of the flow phenomena of advanced aerospace vehicles. The development of advanced aerospace vehicle systems requires well chosen, ground-based experiments and use of the most advanced computational codes. One aerospace vehicle in the concept stage that is expected to result in space-based operation is the Aeroassisted Orbital Transfer Vehicle (AOTV). In 1986, critical wind tunnel tests were completed to assess the effects of the flow impingement problems of various AOTV concepts. The



Wind tunnel test for oil flow patterns for aeroassist flight experiment.

tests, conducted at Mach 10, confirmed the presence of flow impingement on the base region of an aeroassist flight experiment. The impingement was of sufficient severity to affect pitching and would affect the mounted

payloads. Results confirmed the need to apply advanced codes to analyze further the base flow that is scaled to flight conditions.

Materials and Structures. During 1986, a significant effort was focused on the development of advanced thermal protection systems (TPS), with improved durability and high-temperature capability, for use in space transportation systems. In particular, a chemical vapor deposition approach showed great promise for producing high-performance ceramic composite TPS. In addition, new methodology was developed to better predict the thermostructural loading and response of TPS and space structures, in general.

In 1986, research on erectable and deployable structures resulted in the development of a concept for a mobile remote manipulator system that will be used to erect large truss-type structures in space. This highly flexible device is expected to reduce workloads significantly and allow efficient space operations.

Controls and Guidance. This research focused on control of large, flexible space systems, large antennas, and large, segmented astrophysics telescopes. During 1986, algorithm evaluations continued for later validation in the planned Control of Flexible Structures flight experiment. The submillimeter ranging capability of the Spatial, High Accuracy, Position-Encoding Sensor advanced from one to eight positions in determining three-dimensional positioning of large space structures. The Spacecraft Control Laboratory Experiment, which resembles a large offset antenna attached to a model of the Shuttle, continued to validate several unique and innovative control-technique approaches.

Passive integrated optical chip elements for a highly accurate guidance sensor called the Fiber Optic Rotation Sensor were developed. When operational, this sensor will be more accurate and more stable than existing sensors.

Also completed were the hardware and software for a proof-of-concept model of a fault-tolerant control system called the Advanced Information Processing System. This system will provide onboard central control for the Space Station and advanced transportation systems.

Automation and Robotics. The goals of the Automation and Robotics program are to reduce costs, improve performance of future missions, and provide safer, more efficient methods for accomplishing mission objectives

through the use of autonomous control and robotic systems. The program is developing and demonstrating technology applicable to the Space Station, the Orbital Maneuvering Vehicle, the Orbital Transfer Vehicle, the Mobile Remote Manipulator System, geostationary satellite systems, and planetary rovers. It will also address the automation needs of ancillary systems such as prelaunch and mission operations and related ground systems.

The program's two foci are Telerobotics, which will develop and demonstrate technology to evolve teleoperation through supervisory control of in-orbit robots, and Systems Autonomy, which will develop technology to reduce the need for ground control crews and automate onboard subsystems through the use of artificial intelligence and expert systems. Both the Telerobotics and Systems Autonomy parts of the program are involved in a series of demonstrations to validate evolving technological capabilities. They also share a core technology research program that is divided into the areas of sensing and perception, planning and reasoning, control execution, operator interface, and system architecture and integration.

In 1986, the preliminary design and development of the Telerobotic Demonstration Facility was completed, and a sequence of demonstrations for 1988 was defined. Also, significant progress was made in establishing sophisticated hierarchical computer architecture to control a robot.

In the core research program, a prototype of the Programmable Image Feature Extractor was demonstrated which will provide the extensive visual capabilities needed for autonomous robots. Two stand-alone expert systems were integrated; one predicts behavior, and the other is an error diagnostician. This is the first time two separate expert systems have cooperated with each other using a common or shared knowledge base. Other noteworthy accomplishments included rudimentary learning by the expert system planner, DEVISER, and a telerobotic operation involving fuel transfer and node coupling.

In the Systems Autonomy Program, a prototype knowledge base for the Space Station Thermal Control System was demonstrated on a Symbolics 3640 computer using artificial intelligence advanced software tools. The thermal control system is one of the primary subsystems being developed for a future Systems Autonomy demonstration project.

Achievements in corresponding research programs include the development of an expert system with the capability to learn by example, and a prototype spaceborne symbolic and numeric processor. The combined processor uses reconfigurable, fault-tolerant multiprocessor architecture, and is capable of 10 million instructions per second. It will support the COMMON LISP, ADA, PROLOG, and C software environments.

Space Human Factors. This research optimizes the allocation of functions to humans and computers during space missions. High-pressure space suits will allow astronauts to perform immediate, routine extravehicular activity without wasting hours breathing oxygen beforehand to purge nitrogen. Two demonstrator suits were tested and evaluated, and will lead to production of the first hard suits in NASA's history.

A new concept in computer terminals, the "Virtual Workstation," was developed to allow scientists and engineers, working from a ground base, to control, remotely, experiments and equipment in space. Other developments showed that advanced concepts in displays and controls will significantly improve productivity and astronaut safety, both in training and in time-critical situations. Measurements of human strength in weightless conditions were taken aboard a Boeing KC-135. This work was performed in order to establish baseline data for extravehicular activity and tool design.

Computer Science. NASA has experienced explosive growth in the volume of space science data, and computer science is one of the information sciences which advances the management and use of space-derived information. Strained information processing systems have limited the ability to analyze but a small fraction of the archived data. The systems are further complicated by space scientists' increasing practice of integrating sensor measurements and sensor control. To find a solution, research is underway to implement a new, low-cost satellite network using the concepts of telescience for the remote control of and access to data on space experiments. A new scientific data base system will permit uniform remote access to archived space data from dissimilar data base management systems. This concept will be applied first to the Space Telescope project.

NASA has been involved in the development of large, complex software systems. A major focus of computer science research has

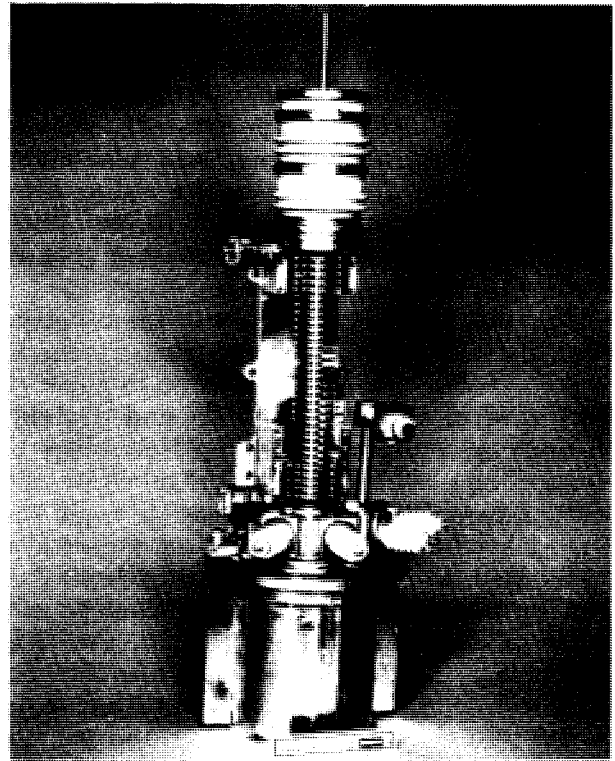
been to develop and implement software management techniques to improve the reliability of software systems and reduce life-cycle costs. NASA developed a prototype of an expert system-based software management aid which includes a memory of past experiences and a feature on lessons learned.

Sensors. Major advances in sensors research resulted in the selection of titanium-doped sapphire as a candidate laser material for use in active remote sensing of terrestrial and planetary atmospheres. It was discovered that the anomalous self-absorption losses observed in these crystals are caused by impurities in the material, and subsequent crystal growth was tailored to rectify this problem. In the detector device area, a silicon array was tested in the wavelength region for space astronomical sensing applications. For detection in the far infrared portion of the spectrum, a mercury-cadmium-telluride alloy frequency mixer was built. In the area of sensor materials research, a new artificial material, an indium arsenide/indium-gallium-arsenide strained layer superlattice shows promise as a new candidate material for sensing. It was grown for the first time by molecular beam epitaxy.

Data Systems. Research on data systems advances the processing, storage, and use of space-derived information. In 1986, the ground-based Advanced Digital Synthetic Aperture Radar Processor engineering model was completed. This system uses over 28,000 integrated circuits, and is tailored to process space synthetic aperture radar data in real time. It performs at a speed four times the original goal, and will be used to support the Magellan and SIR-C flight projects.

NASA is extending DOD-developed very high-speed integrated circuit technology to support civil spaceborne applications. During 1986, computer simulations and hardware verifications were completed, and future plans include the evaluation of circuit technology for ultra-low power consumption and radiation hardness.

Communications. Research in this field seeks to develop microwave and optical communications devices. Fundamental materials research resulted in the development of new reservoir cathodes with longer lifetimes, high-emission current densities, and reduced operating temperatures. These cathodes will have applications in high-frequency/high-power tubes for space and planetary communications and remote sensing. Other



60 GHz traveling wave tube for intersatellite communications.

materials research led to a technique that applies a pyrolytic graphite coating to copper electrodes in a depressed collector. This technique has improved the efficiency of traveling wave tubes by providing a surface with extremely low electron emission properties. A digital filter processor integrated on a silicon chip was developed which replaces the cumbersome and unreliable loop capacitors found in past transponders. The new processor will provide, on command, numerical oscillator control. It is hardened to radiation and is a generic technology that can perform other functions, such as automatic signal acquisition and ranging.

An algorithm was developed to calculate deformations in large, Earth-orbiting antennas caused by repeated cycling through the Sun's shadow. In addition, mathematical solutions provided information to correct physical distortions in antenna reflectors, allowing less active control of large antennas. A 30-GHz integrated gallium arsenide receiver module was fabricated that provides basic receiver functions such as low noise amplification, phase shifting, down conversion, intermediate frequency amplification, and output power control.

Space Flight Systems. Space Flight systems allow flight verification and evaluation of advanced technologies for future space transportation systems. The Shuttle accident, in January 1986, curtailed flight operations and several scheduled technology experiments. However, the Shuttle Entry Air Data System (SEADS) and the Capillary Pump Loop experiments, conducted prior to the accident, provided important data to the technology community.

The SEADS experiment provided accurate measurement of air data across the entry speed range from an altitude of approximately 300,000 feet to landing. The results of this experiment, along with data obtained from five future flights, will be used in the Orbiter postflight aerodynamic performance analysis and data base validation. In addition, the information will help to determine the suitability of the air data system for advanced entry and upper atmospheric flight systems. This important technology advancement and system concept demonstration will influence the design of future entry and flight systems.

In January 1986, the Capillary Pump Loop experiment was flown on the Shuttle, providing systems and component research data important to the development of two-phase, heat-pipe systems that will transport large heat loads on the Space Station and other future spacecraft.

Aeronautics Research and Technology

Beginning with the Wright Brothers' historic flight at Kitty Hawk, North Carolina, the United States has been a world leader in aeronautics research and technology. Since World War II, innovative research and development in aeronautics have been the driving forces behind U.S. economic growth and military power. Today, however, the United States is facing unprecedented challenges from foreign industrial competitors and potential military adversaries. It is important and essential to preserve U.S. aeronautical superiority in the world marketplace and to enhance global security through the excellence of American aircraft.

In 1985, the White House Office of Science and Technology Policy outlined goals for the Nation's activity in aeronautics research and

development that will provide opportunities for significant advances in civil and military aviation by the turn of the century. Focusing on those opportunities, NASA has redirected its research efforts toward emerging technologies that have potential for order-of-magnitude advances in aircraft capability and performance. The agency's goal is to conduct an effective and productive aeronautics research and development program that contributes materially to civil and military aviation.

NASA's Office of Aeronautics and Space Technology conducts an Aeronautics Research and Technology program in disciplines that have been traditionally important to aviation, such as aerodynamics, structures and materials, and propulsion. Also, the Office made considerable progress in applying newer disciplines to aeronautics, such as artificial intelligence and advanced computational simulation. NASA's aeronautics research facilities at Ames Research Center, Langley Research Center, and Lewis Research Center are considered the most comprehensive in the world. These facilities are essential national resources and provide many unique test capabilities for aeronautics research and development. The focus of NASA's Aeronautics Research and Technology program is on providing technology results well in advance of specific application needs, and on conducting long-term, independent research that is not driven by the development and operational pressures often encountered by the Department of Defense and industry.

Both fundamental disciplinary research and vehicle-specific research are conducted at NASA. Disciplinary research may be generically applicable to all classes of vehicles, or may be enabling for entirely new capabilities that are not yet defined. Vehicle-specific research relates to technology that has the potential for enhancing the capabilities of specific classes of vehicles, such as subsonic transport, rotorcraft, high-performance military aircraft, and supersonic and hypersonic vehicles.

Disciplinary Research and Technology

NASA's disciplinary aeronautics research activities provide the technological base for new and innovative ideas necessary for future advances. The research seeks to improve

understanding of basic physical phenomena and to develop new concepts in fluid and thermal physics, materials and structures, propulsion, controls and guidance, human factors, and information sciences.

The increased availability of supercomputers has allowed the discipline of computational fluid dynamics (CFD) to provide powerful analytical, simulation, and predictive tools to address the basic physics of aerodynamic flow fields. New CFD tools are used to advance understanding of the complex flow environment of advanced aircraft configurations, and to permit aerodynamic optimization of new aircraft designs. In 1986, new CFD techniques were used at Ames Research Center to calculate the stream trace lines over an F-16 high-performance aircraft configuration. Use of these techniques resulted in the first complete flow field solution for three-dimensional flows around an actual aircraft configuration. Also in 1986, the world's most powerful supercomputer facility, the Numerical Aerodynamic Simulation (NAS) system, located at Ames Research Center, became operational and was made available to scientists and engineers throughout the United States. Currently, the NAS system uses a Cray-2 supercomputer that can perform 250 million computations a second, and has a 256-million word memory, the largest yet available.

In a related activity, use of the Program Support Communications Network (PSCN), a high-speed data communications network, began in 1986. The PSCN enables real-time access to NASA's supercomputers by government, industry, and universities at locations throughout the United States. It is designed to improve the effectiveness and productivity of large mainframe computers that support the Aeronautics Research and Technology program.

In 1986, use of the National Transonic Facility (NTF) at Langley Research Center improved the ability to validate new CFD computer codes, and several were validated in the NTF during an experiment with a laminar flow glove; subsequently, these codes were used to predict aircraft stability during flight testing of the laminar flow glove on an F-14 aircraft.

Current propulsion research focuses on analytical and experimental work in high-speed fluid flows, turbomachinery internal aerodynamics, chemically reacting and mixed fluid flows, and high-speed inlet and nozzle aerody-

namics. In 1986, an analytical model, developed to simulate internal aerodynamic flows in multistage turbomachinery, was used to analyze flow fields in a high-speed fan stator, high-speed counter-rotating propellers, and in the first stage of the Space Shuttle Main Engine fuel turbine. In related research on internal combustion engines, 160 horsepower was obtained from a 40 cubic inch, single rotor, stratified-charged rotary engine, the highest power density ever achieved in this type of engine.

Because they are lighter and stiffer than conventional metallic aircraft structural materials, composite materials are used increasingly in airframe designs. In 1986, a breakthrough in composite structures research occurred with the fabrication of a geodesic stiffened compression wall panel that is about 30 percent lighter than a skin/stringer aluminum structure, and 40 percent cheaper. Also, considerable progress was made in ceramic composite technology. Ceramics are attractive structural materials because of their strength, low-density, and ability to resist environmental influences, but their brittle nature makes them sensitive to minute flaws and defects. To remedy this problem, Lewis Research Center developed an approach to fabricating strong, tough, ceramic composites that are able to withstand high-temperatures, eliminating the possibility of catastrophic fractures.

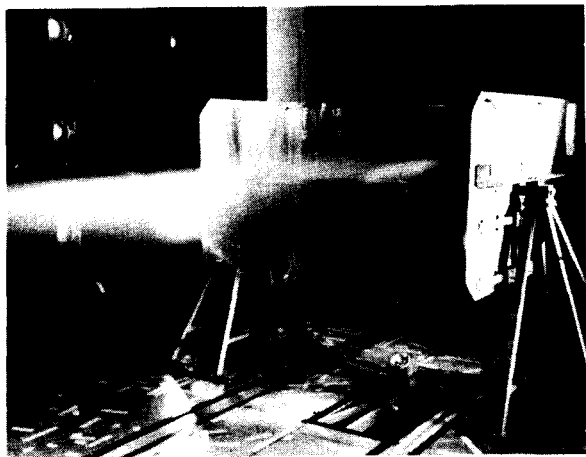
The avoidance or control of unstable aeroelastic phenomena known as divergence and flutter are critical to the successful flight of advanced aircraft. An innovative approach to controlling aeroelastic response involves deforming the wing shape elastically instead of moving control surfaces. The approach has the potential of saving several thousand pounds of structural weight in high-performance aircraft. In 1986, a model of an "active flexible wing" was tested in the Transonic Dynamics Tunnel (TDT) at Langley Research Center, and the predicted advantages of the concept were validated. To support the development of a complete control system for aeroelastic tailoring, additional testing will be conducted in the TDT.

In cooperation with the Federal Aviation Administration (FAA), NASA is conducting research to increase the capacity of the Air Traffic Control (ATC) system in the United States. In 1986, a time-based, terminal-area flow control concept was developed for use in the ATC simulation system at Ames Re-

search Center. The simulation system's algorithm will investigate new ways to use runway capacity, improve fleet operational efficiency, and enhance operational safety within the National Airspace System.

In 1986, research on human factors and automation explored the possibility of using computer systems for artificial intelligence (AI) and radically different methods of control to allow humans and automated machines to work together. An example of man-machine integration is the Army/NASA Aircraft Aircrew Integration (A³I) program, at Ames Research Center, that focuses on the development of predictive methodology for helicopter cockpit system design. In 1986, an initial version of the A³I workstation was developed that generates predictive methodologies for systems design based on mission requirements and pilot training levels.

Studies on natural phenomena as they affect operational flight systems are considered vital to improving flight safety. Current research on storm hazards concentrates on lightning and rain effects, and NASA's Aircraft Icing Program focuses on problems caused by ice. Heavy rain can modify airfoil shapes, change the airflow, and cause the loss of airplane performance to such an extent that safety is affected. In 1986, using a wing



Wind tunnel test of effects of heavy rain on wing section model.

section model, tests were conducted in the Langley Research Center's 4 by 7 meter wind tunnel on the effects of rain on airplane aerodynamics. The data revealed that during periods of very heavy rainfall, maximum lift capacity was reduced by 20 percent. Further tests will be conducted on a larger wing section mounted on an outdoor moving carriage facility. Because little quantitative data ex-

ists that would be useful for engineering analyses, NASA's Aircraft Icing Research program develops analytical and experimental methods to determine changes in aircraft performance due to icing. In 1986, using artificial ice shapes attached to the horizontal tail of a Twin Otter aircraft, air flight tests were conducted at Lewis Research Center to measure changes in the static stability margin of the aircraft. The "double-horned" ice shapes, characteristic of glaze ice, caused the greatest reduction in static stability margin, while the surface roughness produced by rime (granular) ice shapes showed a negligible deviation from the baseline.

Significant progress was made in using the power of new aerodynamic computational methods to analyze low-altitude wind shear. Characterized by rapid changes in wind magnitude and direction, this atmospheric phenomenon is a potential hazard to all aircraft during takeoff and landing. During 1986, a wind shear computer model was applied to several wind shear accidents to improve understanding of the phenomenon and to develop a data base for future investigations. The wind patterns derived from these computations also proved valuable in developing forecast and wind shear models for simulators used in aircraft detection systems and pilot training.

Vehicle Technology

Vehicle-specific research identifies and concentrates on emerging technologies with potential for major advances in aircraft capability and performance. The key or enabling technological developments are described in the specific classes of aircraft, such as transport, rotorcraft, high-performance, supersonic, and hypersonic.

Transport. To advance technology and insure that the United States maintains its preeminent position in the world market for subsonic transport aircraft, NASA conducts research with manufacturers, airlines, and the Federal Aviation Administration (FAA). The immediate goals of the joint research are to establish the technology readiness and designs that will double the fuel efficiency of today's best transport aircraft, while substantially increasing productivity and affordability.

In 1986, as part of the Advanced Turboprop Program, ground testing and flight demon-

strations of a full-scale propfan propulsion system were conducted by NASA and industry. Ground testing of a large-scale (9-foot diameter) propfan was completed in preparation for its flight test on a Gulfstream II twin-jet aircraft. Wind tunnel data from a scale model of the propfan validated the theoretical design and analysis methods used to predict the nacelle and slipstream flow, defined the potential effects on aerodynamic performance for a complete aircraft configuration, and provided safety-of-flight information for the future flight test.

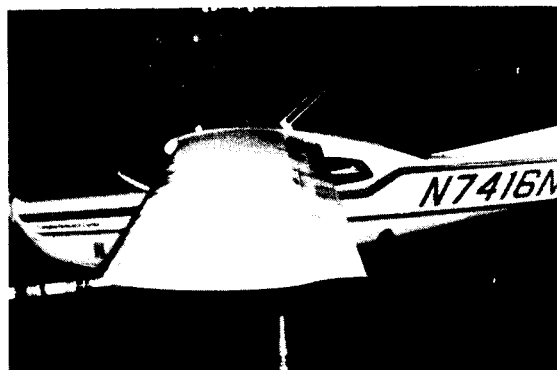
Significant progress was made in the joint NASA/General Electric Unducted Fan (UDF) program that incorporates two unducted, counter-rotating fans with eight highly-swept blades on each fan. This configuration has



Flight test of NASA/General Electric Unducted Fan on modified Boeing 727 aircraft.

promise because it reduces the wake swirl common to single-rotation designs and increases the propulsive efficiency. The UDF system was successfully ground tested, and the first flight tests on a modified Boeing 727 were completed in August 1986. In conjunction with McDonnell Douglas, General Electric is preparing for additional flight evaluations on a modified McDonnell Douglas MD-80 aircraft.

During the cruise phase of subsonic transports, approximately one-half of the total drag is caused by skin friction. The magnitude of friction drag is dependent upon whether the airflow over the aircraft surface is laminar (smooth) or turbulent. By maintaining laminar flow, friction drag is reduced. Three concepts being investigated for maintaining laminar flow over aircraft surfaces include passive natural laminar flow (NLF),



Cessna 210 with natural laminar flow (NLF) wing undergoing wind tunnel testing.

achieved with careful airfoil design, applicable to small airplanes; active laminar flow control (LFC), achieved by suction through tiny slots or perforations in the surface, applicable to large transports; and hybrid laminar flow (HLF) using both active and passive technology, applicable to medium transports.

Wind tunnel and flight testing of a full-size, proof-of-concept NLF wing on a Cessna 210 aircraft was conducted. These tests confirmed that the new airfoil achieves natural laminar flow over 70 percent of the upper and lower surfaces over a broad range of operating conditions. A contoured NLF glove, installed on the wing of a Boeing 757 aircraft, in the region of intense acoustic radiation from the turbofan engine, was also flight tested; this activity confirmed that the laminar flow can be maintained in close proximity to engine noise. In 1986, an important milestone in LFC technology was reached when flight evaluations verified the effectiveness and practicality of using two system concepts to maintain laminar flow over the critical leading edge of the wing, while operating under typical commercial aircraft conditions. Research on viscous drag reduction, conducted during 1986, set the stage for the next phase of research that will concentrate on hybrid laminar flow—combining the best features of active laminar flow control and natural laminar flow design—to achieve substantial drag reduction.

Rotorcraft. The Nation's continued leadership in military and civil rotary wing technology depends on a strong and broad-based research program. In cooperation with other government agencies and industry, NASA conducts a rotorcraft research program in the areas of aerodynamics, structural dynamics, acoustics, guidance, stability and control,

propulsion and drive, and human factors. In 1986, there were a number of significant accomplishments in the areas of noise reduction, improved rotor performance, and high-speed performance.

Reducing rotorcraft noise is essential to obtain community acceptance and to reduce military detectability. In 1986, a new helicopter noise prediction code called ROTONET became available to industry. Also, a major rotor system noise experiment, conducted in a German/Dutch wind tunnel, measured rotor broadband noise, systematically, over a range of conditions in a controlled environment. Results of the noise test are being included in ROTONET. In addition, comprehensive blade-vortex interaction (BVI) data were obtained that will allow the development of a semi-empirical BVI noise methodology.

A tool that will significantly reduce the internal noise caused by helicopter transmissions was developed in the form of a computer program. It will be used for gear tooth contact analysis and determination of gear-cutting machine parameters that will allow production of spiral bevel gears with zero kinematic error. Transmission gears produced as a result of using this software will operate quieter and with less vibration, leading to overall internal noise reduction in helicopters.

In 1986, a major rotor system improvement was demonstrated when advanced-design rotor blades were flown on a scale model UH-60 helicopter. The model blades utilized advanced airfoils, a unique planform shape, and a high degree of twist and aeroelastic tailoring to increase rotor performance and reduce vibrations. Wind tunnel tests showed such a significant performance improvement, especially at high altitudes, that the Army is considering the initiation of a product improvement program for the UH-60A Black Hawk helicopter that incorporates this blade design.

Technology that is used to increase forward flight speed can lead to new and innovative configurations, such as the Tilt Rotor and the X-Wing aircraft. By converting from a standard helicopter mode to a wing-lift mode, it is possible to double or even triple cruise speeds of rotorcraft and vastly improve their productivity. Other benefits of this technology include reduced noise and vibration, and enhanced military effectiveness.

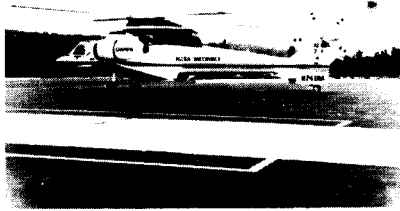
A significant advancement was made in



XV-15 Tilt Rotor Aircraft.

Tilt Rotor research through an experiment that applied circulation control to the trailing edge of a Tilt Rotor wing, which is enmeshed in the downward flow of its rotors. The results verified analytical calculations that the downward force on the wing can be reduced by 25 percent, demonstrating potential for even more efficient and productive Tilt Rotor aircraft.

In August 1986, an important rotorcraft milestone was reached with the fabrication and assembly of the Rotor Systems Research Aircraft RSRA/X-Wing research vehicle. The X-Wing rotor consists of a four blade, extremely stiff rotor system that utilizes circulation control aerodynamics for lift and control. In hover and low-speed flight, the rotor system rotates as a conventional helicopter rotor. For high-speed forward flight the rotor is stopped, converting into a fixed, X-Wing configuration. This joint DOD/NASA program is a continuing effort to advance the state of technology in high-speed rotorcraft flight and several other key technology areas. The X-Wing rotor is a fully composite rotor/wing that consists of extremely thick, load-bearing composite structures. In addition, the advanced, all-digital, quadruply redundant flight control system contains over 60 control effectors that regulate complex pneumodynamics and circulation control aerody-

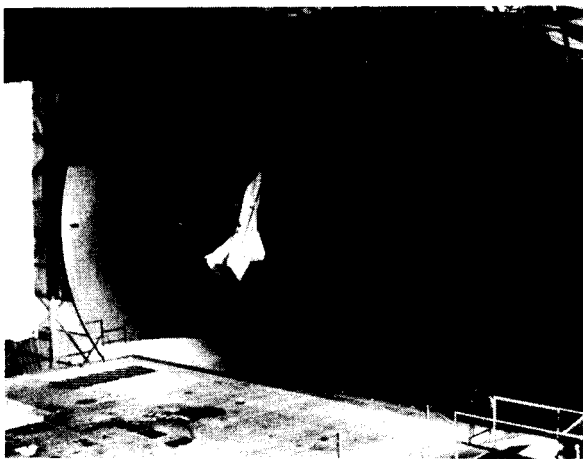


Rotor Systems Research Aircraft (RSRA) X-Wing research vehicle.

namics. In 1986, the RSRA/X-Wing vehicle was shipped to Dryden Flight Research Facility to prepare for flight tests.

High-Performance. Through close coordination with the DOD, NASA's high-performance aircraft research program is structured to support the development of superior military aircraft. The technology spinoffs from such research have consistently advanced the state of civil aviation.

Work on the Highly Integrated Digital Electronic Control (HIDEC) program resulted in the first fully integrated propulsion and flight control system. Tested on a NASA F-15 airplane, the HIDEC system demonstrated that, in addition to very low recurring costs and no weight penalty, significant performance improvements are achievable.



High angle-of-attack wind tunnel testing.

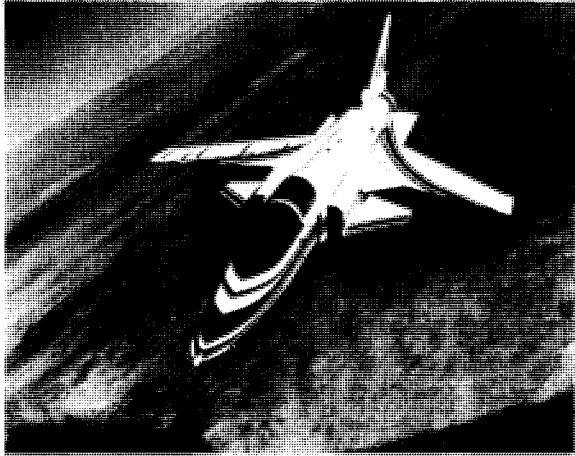
In 1986, work on high angle-of-attack (high-alpha) flight technology for high-performance aircraft was accelerated. Tests in Langley Research Center's 30 by 60 foot wind tunnel, using an F-18 model with propulsive flight control, confirmed the ability to achieve highly stable performance, and full

maneuverability, at an 80-degree nose-up angle-of-attack. The wind tunnel model and simulation investigations were complemented by experimental and computational analyses of forebody flows and vortex flows to study the aerodynamics of high-alpha flight. Water tunnel model tests of the F-18 configuration, conducted at the Dryden Flight Research Facility, confirmed that flow injections in the airstream near the nose of the aircraft can alter vortex flow over the vehicle, allowing favorable aerodynamic changes and overall drag reduction. Currently, preparations are underway to conduct a full-scale flight research program utilizing a modified Navy F-18 aircraft.

Developments in propulsion system thrust-to-weight ratios, propulsive lift control, and understanding low-speed aerodynamics allow new opportunities for state-of-the-art advances in vertical and short takeoff and landing (V/STOL) and short takeoff and vertical landing aircraft (STOVL) technology. In 1986, the United States and the United Kingdom signed a joint research agreement to foster collaboration in the development of advanced STOVL technologies and to reduce the risk associated with developing this type of aircraft. Also, NASA and Canada agreed to test a full-scale STOVL model designated as the E-7. Configured as a transonic aircraft, the model utilizes vectored thrust and thrust augmentation systems for low-speed operations. Wind tunnel tests of the E-7 model conducted at Ames Research Center confirmed the viability of the design as a high-performance fighter aircraft.

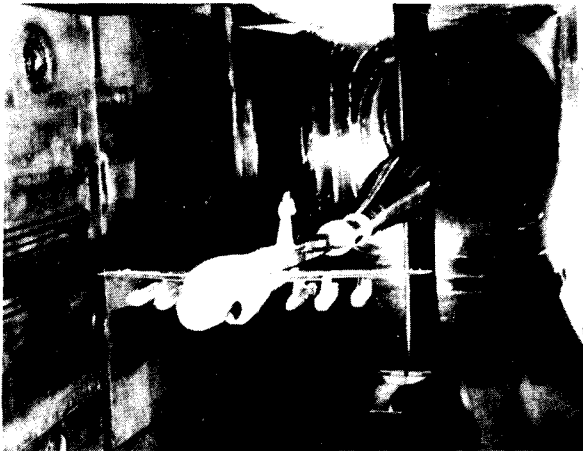
In 1986, the successful integration of advanced technologies that include a composite, supercritical variable camber, aeroelastically tailored wing, canards, and straked flaps were demonstrated in flight tests of the X-29A Forward-Swept Wing aircraft. This aircraft also incorporates an advanced fly-by-wire digital flight control system that integrates active control of flaperons and canard surfaces. Areas of research emphasis include agility, maneuverability, high angle-of-attack stability and control, low-speed control, and transonic aerodynamic efficiency. The X-29A flight envelope was expanded to Mach 1.4 at 40,000 feet, and a follow-on NASA/Air Force flight research program was initiated.

Frequently, NASA's personnel and facilities are used to solve technical problems and improve the operation of military aircraft. In



X-29A Forward-Swept Wing aircraft.

1986, at the request of the Navy, NASA developed and tested aerodynamic modifications to the EA-6B aircraft, and completed wind tunnel studies of the aircraft's configuration at the National Transonic Facility, Langley Research Center. As a result of these tests, recommendations were made for configuration modifications in an airfoil leading and trailing edge, the addition of a small vertical tail extension, and the addition of a wing root/body strake. These changes will improve



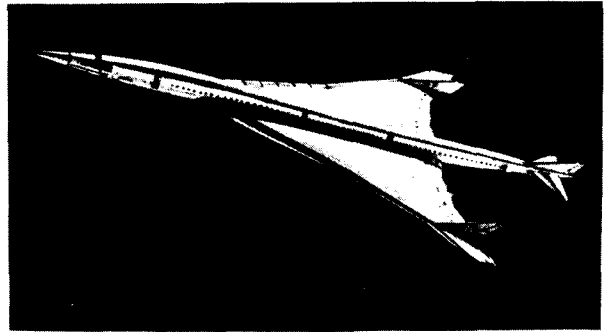
EA-6B aircraft model in National Transonic Facility cryogenic wind tunnel.

the EA-6B lift at low speed, increase the directional control at high angles-of-attack, and reduce stall/spin tendencies. Currently, the Navy is initiating an EA-6B in-flight test program to evaluate the recommended modifications prior to incorporating them into the aircraft fleet.

Supersonic. Achieving supersonic air transportation that is economical has eluded the technical community for some time. However,

the outlook for improved supersonic transportation appears bright. The key enabling technologies for an economically viable supersonic transport include: variable cycle propulsion providing noise levels acceptable to the community and with substantial reduction in fuel consumption and extended-life at high sustained operating temperatures; reduction in airframe structures weight fraction; and increasing cruise life/drag through improved aerodynamics, including supersonic laminar flow.

In 1986, NASA launched the High-Speed Civil Transport Study to identify the most promising concepts for vehicle and propulsion systems for future long-term, high-speed



Artist's conception of high-speed civil transport.

civil transports (Mach 2.0 to hypersonic), and to guide U.S. technology development and production planning. The study will consider market needs and opportunities, economics, airplane concepts, technology projections, and national issues such as safety and environment.

Hypersonic. Establishing the technology foundation for hypersonic vehicles is a major goal of NASA's Aeronautics Research and Technology program. The program focuses on vehicle configuration studies, propulsion, and materials and structures. In addition to earlier progress in hypersonic research, recent accomplishments in these areas have contributed to the state of readiness for the National Aero-Space Plane (NASP) program that is funded jointly by NASA and the Department of Defense. The NASP program will develop a hypersonic flight research vehicle that will be used to validate and demonstrate the successful merging of aeronautics and space technologies. NASA maintains a strong aeronautics research and technology base to support development of the NASP and to advance new technologies for future progress in hypersonic flight.

During 1986, testing in the Langley Research Center's hypersonic propulsion wind tunnels demonstrated that measured thrust levels agreed with theoretical predictions for airframe-integrated, supersonic combustion ramjet (scramjet) engines. Significant progress on variable geometry scramjet configurations was made with the successful testing of the variable geometry inlet configuration at Mach 4, and with a Navier-Stokes flow analysis for the transition area of the engine combustion section. These accomplishments are significant steps toward achieving a hypersonic propulsion system that can be operated over a broad range of speed-altitude combinations.

In related structures research, using a complex brazing process, an advanced technology fuel injection side strut was fabricated for the scramjet engine; and two shortened versions of a full-size, flight-weight article were assembled. This effort demonstrated the feasibility of using this design approach; and preparations are underway to test the strut assembly, using burning fuel, in Langley Research Center's test facilities. Accomplishments in hypersonic structures also included fabricating load-carrying honeycomb panels of high-temperature superalloys. In 1986, a panel array of superalloy honeycomb material was tested successfully, at extremely hot temperatures, under hypersonic flow conditions.

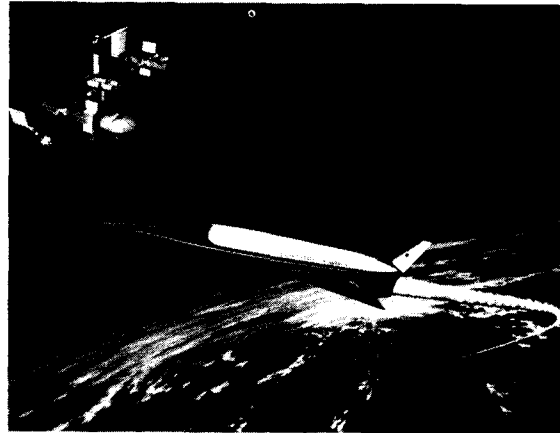
NASA's Numerical Aerodynamic Simulation (NAS) facility lent vital support to the technology development program by calculating the pressure contours on a baseline NASP configuration. The ability of the NAS to provide such an analytical solution for the NASP configuration at high Mach numbers permits the analysis and prediction of vehicle aerodynamic loadings and aerothermodynamic interactions at Mach numbers that are beyond the current capability of other ground test facilities.

National Aero-Space Plane Program

In 1986, NASA and the DOD initiated the National Aero-Space Plane (NASP) program. The goal of the NASP program is to develop hypersonic and transatmospheric technology for a new class of aerospace vehicles that are powered by airbreathing rather than rocket propulsion. The program is structured to provide a validated technology base by the mid-

1990's for single-stage-to-orbit vehicles using airbreathing propulsion as an option for the next-generation manned vehicle. Using the technology developed for the National Aero-Space Plane, a family of vehicles could include a next-generation space transportation system, high-altitude, high-speed military interceptor and reconnaissance aircraft, and hypersonic cruise transport.

Currently, the NASP program focus is on accelerating the ground-based development of key enabling technologies in propulsion, materials and structures, and aerodynamics; evaluating various vehicle configuration concepts; and designing and testing propulsion



Artist's depiction of the National Aero-Space Plane in the vicinity of the Space Station.

system modules and airframe components. This technology development phase should be completed in the late 1980's, and will be followed by a technology readiness assessment and a decision to proceed to the next phase—the development and flight testing of the X-30 research aircraft.

The X-30 will serve as a research vehicle to demonstrate the technologies developed to attain higher altitudes and Mach numbers, and to validate the integration of the technologies into an aircraft. The performance goals for the X-30 vehicle include horizontal takeoff and landing from conventional runways, sustained hypersonic cruise in the atmosphere, and acceleration to orbit and return, with reusable systems.

The unique feature that distinguishes an aerospace plane from a rocket vehicle is the airbreathing propulsion system. The flight corridor for an airbreathing aerospace plane is substantially lower in altitude over most of the trajectory because of the need for higher density air to pass through the engine to pro-

duce the required thrust. As a result, an aerospace plane must have an airframe and engine structure that can withstand much greater pressures and thermal loads than a rocket-powered vehicle.

The NASP is characterized as an airplane that will fly to orbit, but there are major differences between it and previous aircraft. In addition to the advanced airbreathing propulsion system, the degree of integration required between the airframe and the propulsion system is substantially more complex due to the strong interdependence of the vehicle and engine flow fields. The NASP design takes advantage of the flow compression developed through the vehicle forebody flow field to produce the elevated pressures required for the combustion process, and uses the aft undersurface of the vehicle as part of the engine exhaust nozzle. As a result, the performance of the airframe and the engine is strongly coupled.

The primary enabling technology for the NASP is the scramjet, which is needed for airbreathing operation at speeds beyond Mach 6. Scramjet design and operation have been optimized in subscale tests for internal geometric configuration, fuel injection and mixing, and ignition and combustion efficiency. Although there are several facilities in which the lower speed propulsion technology can be verified, there are no ground facilities for testing the scramjet beyond Mach 8. Therefore, performance predictions for the higher Mach numbers will be based on computational analyses verified by partial simulation of selected parameters in wind tunnels. The X-30 flight research program is necessary to continue developing and demonstrating this hypersonic propulsion technology.

Both experimental and computational tools are being used to identify and develop technologies, but computational capability is playing a more significant role than in the past. Because wind tunnel simulation capability is limited, computers will be the primary tool used for designing the NASP and analyzing very high Mach numbers and altitude conditions. The Numerical Aerodynamic Simulation system, and other supercomputers at NASA's Centers, government laboratories, and industry facilities are being used extensively for analyses of NASP configuration aerodynamics, trajectories, controls, structural concepts, and subsystem benefits and penalties. With this capability,

full three-dimensional viscous flow fields are being calculated for candidate configurations, including internal flows, boundary layers, and shock interactions.

A variety of design approaches for both the airframe and engine are being evaluated, including the use of structures made of advanced materials that carry both pressure and thermal loads, and insulated structures, in which low-temperature, load-carrying materials require a thermal protection system. High-temperature metals, advanced carbon-carbon, and high-temperature composites are being evaluated for use on the fuselage, tank, and engine structure.

For areas of the vehicle where thermal energy will adversely affect available structural materials, such as the leading edges of engine fuel struts, inlets, control surfaces, and fuselage nose, cooling will be required. Various cooling techniques and technologies are being evaluated for application to the X-30 vehicle. Techniques that are under study include regenerative cooling that requires the circulation of cold fuel through the aircraft skin to absorb heat before injecting it into the engine and film cooling for localized hot spots, heat pipes, and liquid metal heat exchanges.

The NASP program will also require advances in the area of highly-integrated control systems. With the exception of airbreathing propulsion, technology developed in the NASP program should be directly transferrable to future rocket-powered space transportation systems.

Department of Defense

The loss of the Space Shuttle Challenger on January 28 shocked the Nation, and resulted in an unprecedented setback for the U.S. space program. The grounding of the Shuttle fleet severely impeded access to space for the Nation's military, scientific, and commercial payloads. Further compounding the problem were the two Titan 34D launch failures, resulting in the cessation of this launch capability for the year. This series of accidents led to the development of a national space launch strategy that does not rely on a single launch system as the primary means to reach space.

Over the past year the Department of Defense (DoD), NASA, and the Department of Transportation, as well as the commercial and scientific communities, have worked closely to develop the Space Launch Recovery Plan that will balance use of the Shuttle and expendable launch vehicles (ELV's), to achieve efficiency and economy. Shuttle launches will be used to exploit the flexibility of having man-in-the-loop, while ELV's will be used for more routine missions or for those involving higher risks.

The purpose of the recovery plan, now well underway, is to satisfy national security requirements as well as scientific and commercial launch needs. The DoD commitment to the recovery plan places renewed emphasis on use of expendable launch vehicles. The plan includes procurement of a fourth orbiter, procurement of 23 Titan IV's (previously known as the Complementary Expendable Launch Vehicle (CELV)), with a production rate of five to six Titan IV vehicles per year, and procurement of 12 medium launch vehicles (known as the Delta II) over the next three years. While procurement of the Delta II is required to support launches of Global Positioning System (GPS) satellites, this effort has also been structured to stimulate a commercial space launch capability. The plan also includes ensuring that some payloads are dual-compatible with the Shuttle and EVL's; transferring some Shuttle missions to ELV's; and expanding to a Titan IV launch capability at both the east and west coast launch facilities.

While the ultimate goal of the Space Launch Recovery Plan is to close the gap be-

tween requirements for access to space and capability for launch, merely acquiring additional launch vehicles does not solve the problems of assured access to space. A mixed fleet of launch vehicles is being developed and procured, and will be maintained; future launch systems must be free of single point system failures, so major components of one launch vehicle are independent of another's design; and future heavy-lift launch requirements are being analyzed and supported. In addition, innovative new ways for payload and launch vehicle processing and integration should be devised, approaching the methods used in cargo aircraft systems, to ensure faster, more reliable turn-around of space systems and associated launch facilities. The future U.S. space transportation system designs must be driven by the need for operations and support efficiencies, in order to achieve substantial reductions in the recurring costs of space launch operations. Far-term national space launch alternatives are currently being developed in the joint DoD/NASA Space Transportation Architecture Study (STAS). The STAS is examining all aspects of space launches that include requirements, vehicles, operations, and technology; it will develop a framework for technological advances in areas such as propulsion, lightweight structures, automated operations, and advanced avionics. Incorporation of these advances into innovative system concepts will allow the United States to define a more cost-effective space launch program for the post-1995 period.

Space Activities

Military Satellite Communications

MILSATCOM. Military Satellite Communications requirements are satisfied with a combination of satellite systems that provide a variety of services in several frequency bands. In the Ultra High Frequency (UHF) band, the Fleet Satellite Communications (FLTSATCOM) System, augmented by leased

satellites (LEASAT), provide low-capacity, worldwide command and control to a large community using small, mobile terminals. The Air Force Satellite Communications (AFSATCOM) System provides special capabilities to U.S. nuclear forces, using communication packages on FLTSATCOM and other host satellites. At the Super High Frequency (SHF) band, the Defense Satellite Communications System (DSCS) provides high capacity command and control, intelligence, and multichannel communications service to a wide range of strategic, tactical, and non-DoD users. In the future, using the Extremely High Frequency (EHF) band, the Milstar Satellite Communication System will provide highly survivable and enduring thin line communications for critical users. During 1986, MILSATCOM focused on enhancing the survivability and improving the availability of service to all users. In addition, planning efforts were initiated on two new programs; one is expected to ensure interoperable communications among all DSCS users under the most severe, hostile conditions; and the other is designated to satisfy very high speed digital communications requirements. To integrate current activities with future needs, a comprehensive MILSATCOM architecture document was prepared. This document describes the plans and programs needed to ensure continued MILSATCOM service through the year 2010.

Defense Satellite Communications Systems (DSCS). The DSCS constellation provides worldwide coverage between latitudes 75° north and 75° south. In 1986, the second DSCS III satellite became operational, allowing the DSCS system to evolve into a more robust system. This new capability, which significantly enhances DSCS support in the Atlantic area that covers Europe, Eastern United States and the Caribbean, includes increased capacity, flexibility, and wartime survivability.

Replacing older, Phase II satellites with jam-resistant, electromagnetic pulse (EMP) hardened Phase III satellites was delayed due to a lack of launch capability. However, there are sufficient Phase II satellites in orbit, with reliabilities greatly exceeding specifications, to allow continued service.

During 1986, the United States and the United Kingdom conducted a joint evaluation of requirements for a new survivable, jam-resistant modem for use in all strategic and tactical terminals of their respective mil-

itary forces. Referred to as the Universal Modem, this equipment will ensure survivable, interoperable communications, and will operate in the worst-case wartime environments.

A new concept for a ground terminal was considered using a "modular building block" design to allow near real-time adjustment (tailoring) of its operational configuration. The adjustment allows the terminal to operate using any of the standard DSCS modulation and access techniques. A limited number of terminals are expected to provide a quick reaction capability to meet urgent critical requirements. A final decision on procurement is pending.

The ground environment of the DSCS was expanded and modernized for increased survivability, capacity, and reliability. In 1986, 14 new Medium Earth terminals were accepted for deployment, and 24 additional terminals are expected by 1988. Acquisition of 12 net control and 83 nodal terminals for the DSCS Frequency Division Multiple Access Control Subsystem was initiated, and deliveries will extend through 1989. The fifth and final DSCS Ground Mobile Forces Control Link was delivered to Oakhanger RAF, in the United Kingdom. In addition, acquisition of subsystems and components for increased communications capacity and more responsive and survivable control subsystems continued.

Air Force Satellite Communication System (AFSATCOM)/Single Channel Transponder (SCT). The AFSATCOM is a SATCOM capability that provides reliable global communications between the National Command Authorities and nuclear-capable forces. The system includes a space segment composed of transponders on host satellites, a terminal segment consisting of fixed and transportable ground terminals and airborne terminals; and a control segment. The Single Channel Transponder Injection System is a new capability evolving as DSCS III satellites become operational, which will provide a limited number of command elements with a highly survivable capability to broadcast essential messages to a large number of forces. There are three sites under contract for the installation of the Single Channel Transponder Injection (Broadcast) capability; the remaining injection sites will be under contract in 1987. Also, efforts are under way to procure additional receiver equipment for ICBM Launch Command Centers and selected nonstrategic nuclear forces; contract

award is expected in 1987.

Milstar. Milstar is a multichannel, Extremely High Frequency (EHF)/Ultra High Frequency (UHF) satellite communications system that will provide survivable, enduring, jam-resistant, and secure voice/data communications for the President, Joint Chiefs-of-Staff, and the Commanders-in-Chief. It will be used for the worldwide command and control of U.S. strategic and tactical forces in all levels of conflict. Milstar satellites, which contain special survivability features, will be launched into high and low inclination orbits to provide full Earth coverage. Full-scale development of the space and mission control segments continued in 1986, with critical design reviews scheduled for mid-1987 and early 1988. Detailed planning for payloads and their integration into the satellite bus received major emphasis. Nuclear-hardened Milstar terminals will be provided to command facilities, surveillance outposts, and to strategic and tactical forces during the 1990's. Modifications to existing AFSATCOM terminals that are currently in progress will provide an early jam-resistant UHF capability, and a smooth transition between AFSATCOM and Milstar. When completed, Milstar will provide the Nation's most survivable wartime communications capability. The Air Force is the lead service for the procurement of Milstar satellites, the dispersed mission control network, and most of its own terminals. The Army and Navy also have their own terminal development and procurement programs. The terminal programs of all three services are coordinated through the Navy's Joint Terminal Program Office, which has the responsibility to ensure interoperability and common specifications among the three designs.

Fleet Satellite Communications System. This system provides low-capacity voice and data capabilities for small, mobile users, such as the Navy and those who require man-pack terminals. This satellite system consists of five FLTSAT satellites and three leased satellites (LEASATS) in synchronous equatorial orbits which provide worldwide coverage between 70° north latitude and 70° south latitude.

FLTSAT spacecraft will approach their end-of-life in the early 1990's while the requirement for UHF MILSATCOM services is projected to rise significantly and continue through the foreseeable future. To satisfy these requirements, planning began for a

follow-on satellite to provide continued service through the 1990's. Two follow-on UHF spacecraft will provide a greater number of 25-KHz and 5-KHz channels than the current FLTSAT/LEASAT combination. Contract award for procurement of these satellites is expected in 1987.

After numerous delays caused by launch failures of the Space Shuttle, and Delta and Titan 34D rockets earlier in the year, the Fleet Satellite (FLTSAT) 7 was launched on December 4, 1986. FLTSAT 7 was launched out of sequence ahead of FLTSAT 6 because FLTSAT 7 carried an additional payload, the FLTSAT Extremely High Frequency package (FEP), designed to allow testing of Milstar-compatible EHF terminals. EHF terminal testing will begin in the spring of 1987.

Satellite Laser Communications. The Satellite Laser Communications (SLC) system is a joint technology demonstration effort between the Navy and the Defense Advanced Research Projects Agency (DARPA) to provide the capability to communicate with a submerged submarine from space using a laser beam as the transmitting medium. To date, the basic capability has been proven by sending messages to a submerged submarine from an aircraft using green laser light. An operational system will use blue laser light which provides greater transmission efficiency. An aircraft-to-submarine test using a blue laser, scheduled for the spring of 1988, will complete the joint technology demonstration. SLC has been approved as a Navy new-start program for 1988.

Navigation and Geodesy

Global Positioning System (GPS). No additional GPS satellites were launched during 1986. The last development GPS satellite, Navstar II, was launched in October 1985. Currently, five GPS developmental satellites are performing well. Two developmental satellites, operating well beyond their design lifetimes, showed the effects of age and performed marginally. Procurement of operational satellites was in its fifth year under a multiyear, 28 spacecraft, contract. The first operational launch is scheduled for 1988, with full operational capability planned for 1990. These dates reflect an approximate 2-year delay due to the lack of Space Shuttle Launch capability.

In June 1986, Low Rate Initial Production (LRIP) of GPS user equipment was approved by the DoD Joint Requirements and Management Board. LRIP will continue through 1988, pending verification of correction of reliability and maintainability problems encountered during 1985 field testing. In 1989, another DoD review is planned for user equipment performance before approving full-rate production. In 1986, the master control station, which supports the current GPS constellation, became operational at the Consolidated Space Operations Center at Falcon Air Force Station, Colorado. Full operational capability of the control station is planned concurrent with full GPS capability.

Geodetic and Geophysical Satellite. In September 1986, the Navy's Geodetic and Geophysical Satellite (GEOSAT) completed its primary 18-month mission, which was to provide the Navy and the Defense Mapping Agency with a large quantity of global altimeter data to be used in improving the Earth's gravitational models. At the conclusion of this primary mission, GEOSAT was repositioned to a new orbit. This new orbit, with a 17-day repeat cycle, is the same one used by NASA's previous SEASAT, and is a favorable one for collecting oceanographic topography data. Data obtained will assist in the measurement of significant wave heights, surface winds, and ocean thermal features. GEOSAT will continue this valuable oceanographic mission until it reaches its end-of-life.

Meteorology and Oceanography

Navy Remote Ocean Sensing System (N-ROSS). Near the end of 1986, the Navy had been reviewing contractor proposals for the construction of N-ROSS, with an expected contract award to have been early 1987. In late December 1986, the Secretary of the Navy canceled the N-ROSS program due to severe budgetary constraints. Therefore, N-ROSS was not a development program at the end of 1986. However, the Navy plans to bring the proposed program before the Defense Acquisition Board (DAB) and the Defense Resources Board (DRB) in early 1987. If approved, the N-ROSS satellite is planned to have four principal sensors, a Low-Frequency Microwave Radiometer, a Special Sensor Microwave Imager, a precision radar altimeter, and a NASA-developed scatterometer. This

sensor suite would give N-ROSS the capability to measure sea surface temperatures, ocean surface winds, significant wave heights, ocean fronts and eddies, polar ice conditions, and atmospheric water vapor. Under the original Navy plan, N-ROSS was scheduled for launch in September 1990. Under a revised plan, launch is now scheduled for mid-1992.

Defense Meteorological Satellite Program (DMSP). DMSP is the DoD's most important source of weather data. In 1986, DMSP reached several significant milestones. The first two Block 5D-2 satellites, F-6 and F-7, launched in December 1982 and November 1983, respectively, exceeded expected on-orbit life. Also, in late 1986, the F-9 satellite was delivered, joining F-8 in ground storage awaiting launch requirements. Production of follow-on satellites, including a successful multiyear procurement, continued. In July 1986, a contract was awarded to RCA for the prototype improved Block 5D-3 satellite, S-15. Also in 1986, initial operational capability was achieved for the interactive Satellite Data Handling System at the Air Force Global Weather Central, Offutt Air Force Base, Nebraska.

Surveillance and Warning

Early warning satellites, complemented by ground-based radars and sensors, warn of potential ballistic missile attacks. In 1986, an Air Defense Initiative program was organized to develop technologies to detect, identify, and negate air threats to North America, including cruise missiles. Airborne, ground-based, and space-based surveillance techniques that will allow detection of cruise missiles are under study. Included in the studies is the feasibility of detecting and tracking cruise missiles from space platforms using radar and infrared sensors. Surveillance and warning for continental air defense is currently provided by a system of radar sites and Sector/Regional Operations Control Centers located in the United States and Canada. The radar systems include the Joint Surveillance System and, under development, the North Warning System, and Over-the-Horizon Backscatter Radar System. The joint Air Force/Defense Advanced Research Project Agency's Teal Ruby program is designed to detect airbreathing vehicles from an orbiting platform.

Antisatellite (ASAT) Program. The Space Defense program continued to develop a low-altitude, miniature-vehicle ASAT system. The primary purposes of an ASAT capability are to deter threats to space systems belonging to the United States and its allies, and to deny use by an adversary of space-based systems that provide support to hostile military forces. ASAT will be launched from F-15 aircraft. As a result of a FY 1986 congressional restriction prohibiting testing against objects in space, the testing effort was reoriented. Infrared phenomenology flights, to assess the performance of the sensor at low altitudes, were successfully completed in August and September 1986.

Strategic Defense Initiative

The Strategic Defense Initiative Organization (SDIO) has established an integrated program around the five key areas of Surveillance, Acquisition, Tracking, and Kill Assessment (SATKA); Directed Energy Weapons (DEW); Kinetic Energy Weapons (KEW); Survivability, Lethality, and Key Technologies (SLKT); Systems Analysis and Battle Management (SA/BM). It has also established the Innovative Science and Technology Office (IST) to manage fundamental research. Each represents an essential component in the development of a robust strategic defense system.

KEW sponsored two successful flight tests in 1986. The first experiment conducted a hit-to-kill intercept on a missile target at low altitude, using a millimeter wave radar seeker in the interceptor. The program, called Flexible Lightweight Agile-guided Experiment, made three successful intercepts in three attempts, the last of which destroyed an actual air-launched reentry vehicle. In the second experiment, critical space observation data were obtained, and an actual space intercept was conducted.

U.S. Army Strategic Defense Command (USASDC). The Army executing agency for SDI, USASDC, conducts a continuing research program to build a strong technological foundation from which a wide range of strategic defense options can be developed. In 1986, high Endoatmospheric Interceptor and Exoatmospheric Reentry Vehicle Interceptor System contracts were awarded. The Free Electron Laser initiated a major new experiment at White Sands Missile Range; and the

Neutron Particle Beam Accelerator Test Stand attained operating levels making it the most powerful ion beam generator in the world.

Space Transportation

Expendable Launch Vehicles (ELV's). DoD proceeded with activities that will lead to the acquisition and launch of 23 Titan IV's between 1988 and 1993. By complementing the Space Shuttle, they will support the President's national policy for assured access to space, and help to reduce the backlog of DoD payloads that were scheduled for launch on the Space Shuttle.

Fifty-six existing Titan II missiles were moved to storage at Norton Air Force Base, California. Fourteen of the Titan II's will be converted to a space launch configuration to support small payloads that require unique orbits. The remaining Titan II's are available for future conversion.

A program was initiated to acquire a Medium Launch Vehicle to support the Global Positioning System (GPS) program that faces significant launch delays as a result of the Challenger accident. A contract for the Delta II to launch 20 GPS satellites will be awarded in early 1987.

Significant progress was made in recovering from a Titan 34D failure in April 1986, including development and verification of state-of-the-art, non-destructive tests for large solid rocket motors.

Space Shuttle. The close working relationship between the Department of Defense and NASA on the Nation's Space Transportation System proved invaluable during the period of crisis following the Challenger accident. Together, an approved Shuttle launch manifest was developed that meets, as much as possible, priority DoD and NASA satellite needs when Shuttle flights resume in 1988. The DoD placed the Vandenberg Shuttle Launch Site in minimum facility caretaker status to allow the remaining orbiter fleet to concentrate on east coast operations and to gain maximum efficiency in reducing the backlog of DoD and NASA payloads. Current funding will facilitate reactivation of the Vandenberg complex when the requirements and Shuttle capabilities dictate.

Upper Stage Programs. The Space Shuttle utilizes upper stages to boost payloads from low Earth orbit to higher orbits up to geosy-

nchronous (GEO) and beyond. The current family of Shuttle-compatible upper stages include the commercial Payload Assist Modules, which can carry 450 to 1,400 kilograms to GEO and Air Force Inertial Upper Stage (IUS), capable of boosting 2,300 kilograms to GEO. As a result of NASA's cancellation of the Shuttle-Centaur Program in 1986, the DoD began efforts to acquire more capable (2,430 to 4,550 kilogram class) upper stages to meet DoD Shuttle mission needs in the 1990's.

Advanced Spacecraft Technology. The primary objective of this activity is increased satellite survivability, autonomy, performance reliability, and lifetime. The program focuses on computers, electronics, and power subsystems. In 1986, the first phase of the program to develop technology for space-qualified Very High Speed Integrated Circuits was successfully completed, and the qualification of a longer life, space-qualified battery was completed. This battery design has resulted in a 5-year life test program.

Space Test Program. Three Space Test Program (STP) missions that carried 19 DoD experiments remained in orbit collecting data applicable to the design of future DoD space systems. In 1986, two experiments were flown on the Shuttle, providing information on contamination in the Shuttle environment, and the effects of space on large structures. In November 1986, the Scout-launched Polar Experiment and Auroral Research Satellite carried three additional experiments into space to image the aurora, and provide forecasts of communications disturbances in the polar region. STP initiated procurement of a dedicated DoD Spartan experiment carrier through NASA's Goddard Space Flight Center. The first flight will occur in 1989.

Military Space Crews. As space-related technology improves, the role of man in supporting and using that technology will mature. Military functions in space may closely parallel those of civilian counterparts in such areas as transportation, observation, construction, and satellite launch or repair. The Department of Defense continues to work with NASA to train military space crew members, and to solve many human-centered space technology problems. In 1986, the Air Force formulated a Military Man in Space Program to help assess the operational capabilities of man in space. The Air Force also extended prior exploratory development into advanced technology development of mili-

tary-specific modifications of equipment and new systems to ensure crew performance and protection in the space environment.

Aeronautical Activities

Fixed-Wing Programs

Bomber Development (B-1B). In June 1985, the first B-1B was delivered to the Strategic Air Command. In September 1986, 15 operational aircraft were delivered to Dyess Air Force Base, near Abilene, Texas. As part of the Strategic Air Command's strategic deterrent force at Dyess AFB, the first B-1B's were on constant alert status. Testing of B-1B's continues at Dyess AFB and Edwards AFB, California. Full operational capability will occur in 1988 with the delivery of the 100th and final B-1B.

Advanced Tactical Fighter (ATF). The ATF program is developing the next-generation Air Force fighter to counter the Soviet threat projected for the late 1990's and beyond. As a follow-on to the F-15, the ATF is being designed to penetrate high-threat enemy airspace and support of the air-land battle forces with "first-look, first-kill" capability against a technologically advanced, numerically superior enemy. The ATF's improved capabilities will be made possible by significant technological advances in the areas of signature reduction, aerodynamic design, flight controls, materials, propulsion, sensors, and integrated avionics. It will reach an initial operational capability in the mid-1990's.

In April 1986, the ATF program was restructured to include flying prototypes and ground-based avionics prototypes in the Demonstration/Validation (Dem/Val) phase of the program. The restructured program implements Packard Commission recommendations, emphasizes fly-before-buy, a competition, and provides the means to reduce technical and cost risks prior to entering fullscale development in 1991.

In October 1986, the ATF program completed a Joint Requirements Management Board Milestone I, and received Office of Secretary of Defense approval to award the Dem/Val contracts. Contracts were awarded to Lockheed and Northrop, and flight demonstrations of their prototype aircraft, designated YF-22A and YF-23A respectively, will begin in 1990. General Electric and Pratt

and Whitney are providing the prototype engines for the ATF aircraft.

C-17. The C-17 aircraft will provide a capability for intertheater airlift of light and heavy combat units, including outsize equipment, and direct delivery into the forward areas. In the late 1990's, the C-17 is expected to satisfy the shortfall from the intertheater airlift requirement identified in the Congressionally Mandated Mobility Study. It will provide an increase in intratheater capability. The C-17 is now in its second year of full-scale development, with first flight planned in 1990, and an initial operational capability in 1992, using 12 aircraft.

Remotely Piloted Vehicle. The Navy and Air Force are jointly developing a medium-range, unmanned reconnaissance vehicle. The Navy is developing the unmanned vehicle, and the Air Force is developing an electro-optical sensor suite to be carried by Air Force and Navy manned and unmanned tactical reconnaissance vehicles. In 1987, two contractors will be selected to participate in a competitive fly-off of their unmanned vehicles that will occur during 1988.

Cruise Missile Programs

Air Launched Cruise Missile (ALCM). The ALCM is a long-range, subsonic missile designed for deployment from the B-52G and H models. An inertial guidance system, which is updated after launch by terrain correlation matching, guides the missile to the target. A total of 1,715 missiles have been delivered to the Strategic Air Command. Missiles are currently deployed at five B-52 bases, and deployment is under way at two additional bases.

Ground Launched Cruise Missile (GLCM). Air Force deployment of GLCM's continues on schedule. Initial operational capabilities have been established in the United Kingdom, Italy, Belgium, and the Federal Republic of Germany. Deployment to the Netherlands is on schedule for 1988.

Helicopter Programs

AH-64A (Apache) Advanced Attack Helicopter. In November 1986, the 162nd AH-64A Apache helicopter was delivered to the Army. The first AH-64A attack helicopter

battalion was fielded at Ft. Hood, Texas in April 1986; the second battalion was fielded 120 days later, and by November 1986, a third battalion based at Ft. Hood began accepting aircraft and equipment in preparation for fielding. These aircraft are being delivered in compliance with the fourth production contract, which will procure 309 aircraft. Currently, contract negotiations are under way for procurement of aircraft as the Army moves closer to its procurement objective of over 593 AH-64's.

CH-47 Modernization. In April 1985, a 5-year multiyear procurement (MYP) contract was awarded to modernize 240 CH-47A, B, and C model cargo helicopters to the D model configuration. The CH-47D provides substantial improvements in reliability, availability, maintainability, flight safety and survivability. By November 1986, as the program moved through the second year of the 5-year MYP, 58 CH-47's had been delivered to the Army. A proposed second MYP contract from 1990 to 1992 would complete a procurement objective of 472 CH-47D's.

UH-60A Blackhawk. By November 1986, a total of 826 UH-60A's had been accepted by the Army. These aircraft were distributed to priority units in the United States, Europe, Japan, Korea, Panama, the Army National Guard, the Army Reserve, and to the Training and Doctrine Command. The UH-60A is in its third MYP contract.

Light Helicopter Family (LHX). The Army initiated a technology development program called Advanced Rotocraft Technology Integration (ARTI). ARTI supports full-scale development in 1988 of a family of light helicopters, planned for deployment in 1995. Previous research efforts have shown that an integrated and automated cockpit, and associated electronic architecture, will provide the LHX and existing helicopters with improved characteristics. The Army awarded contracts to two teams for full-scale development of the LHX engine, designated the T800. The T800 is a 1,200 shaft horsepower, nonregenerative, free power turbine, turboshaft engine of advanced technology and high power to weight ratio coupled with low-specific fuel consumption. In August 1986, the Army awarded contracts to two teams for the purpose of reducing risk for initiation of the LHX competitive development program. These risk-reduction efforts are concentrated in the areas of simulation, wind tunnel and

Mission Equipment Package design, and brassboard demonstrations. All efforts are designed to ensure that LHX will enter the competitive development phase with no high-risk technology components. Full-scale development of the LHX airframe and mission equipment will begin in 1988. The Army will conduct a competitive program for LHX through development, and competition for production contracts begins with the third lot buy.

V/STOL Programs

V-22 Osprey (formerly JVX). The Osprey is designed to provide the Marine Corps, Navy, Air Force, and Army with a multimission Vertical/Short Takeoff and Landing (V/STOL) capability for the 1990's and beyond. It will satisfy operational requirements such as Marine Corps assault vertical lift, Navy combat search and rescue, Air Force special operations, and Army medium cargo assault lift. In April 1983, the Preliminary Design Phase began; in 1986, a decision leading to full-scale development was made. Powered model, aeroelasticity, and large-scale rotor performance tests were completed. Results of these tests will lead to detail design of the Ground Test Vehicle.

Aeronautics Technology

Microwave Landing System (MLS). MLS is the precision approach landing system of the future. It will replace the existing instrument landing system (ILS) and precision approach radar by the year 2000. Both fixed and mobile MLS ground equipment will be acquired as well as MLS avionics for DoD aircraft. The Federal Aviation Administration has overall responsibility for the national MLS program, and the Air Force was designated the lead service for the DoD. In 1986, the Air Force completed preparation of Requests for Proposals for modified commercial MLS avionics and a mobile MLS. The modified commercial MLS avionics will be used in cargo, tanker, trainer, and support aircraft. The mobile MLS will replace the existing fixed and mobile precision approach radars. The modified commercial avionics Request for Proposal was released in December 1986, and a contract award is scheduled for May

1987. In March 1987, the mobile MLS Request for Proposal will be released concurrently with the FAA's Request for Proposal for Fixed Base MLS equipment. The FAA Base MLS Request for Proposal will include equipment for the DoD, and contract award for both systems is planned for early 1988. An MLS avionics architecture study, completed in 1986, considered MLS avionics alternatives for high-performance aircraft that are environmentally and space-constrained. As a result of this study, the Air Force will conduct a concept definition effort for a high reliability (20,000 hour, mean time *between* failure) MLS/ILS receiver. The ILS capability will be retained until the transition to MLS is completed in the year 2000.

Advanced Fighter Technology Integration (AFTI). In 1986, the AFTI/F-16 completed its last full year of testing at Edwards Air Force Base. Its Automated Maneuvering Attack System provides highly accurate maneuvering attack against ground targets from very low altitudes and improved air-to-air effectiveness. Technologies in the AFTI program will be used to improve the performance of future aircraft such as the Advanced Tactical Fighter.

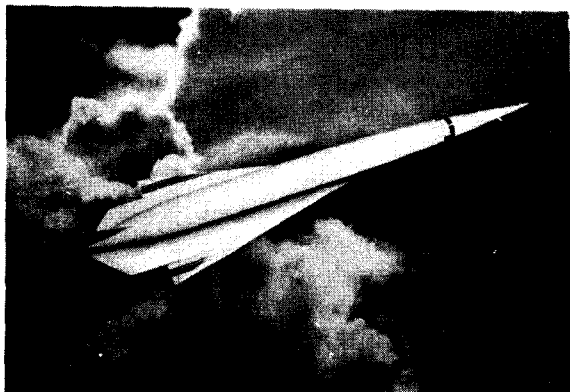
X-29 Advanced Technology Demonstrator. The forward-swept wing X-29 aircraft has completed its second year of flight testing. This innovative program demonstrates advanced high-risk, high-payoff technologies for future consideration. Exploitation of these technologies will improve future fighter aircraft performance and will reduce the time, risk, and cost of future development. It is a joint DARPA/NASA/Air Force program that expands significantly the existing data bases for advanced composite research, aerodynamic and structural analytic design methods, design techniques of digital flight control systems, systems integration, and test and evaluation capabilities. The flight testing is being conducted by a joint Government/industry team at NASA's Dryden Flight Research Facility at Edwards Air Force Base, California.

During 1986, the X-29A completed more than 85 test flights to expand fully its flight envelope to a maximum altitude of 40,000 feet and a maximum Mach number of 1.45. Considerable testing was conducted at high-dynamic pressures, a combination of low altitude, high speed, and high-G load factors that stressed the capability of the aircraft

structure, flight control system, and aerodynamic stability. Test results indicate that vehicle drag levels are significantly lower than predicted, and that vehicle stability is better than analysis has predicted through the flight envelope. A follow-on program has been defined and approved to flight test the second X-29A aircraft in a high angle of attack program.

National Aerospace Plane (NASP). This joint program including DARPA, Air Force, Navy, Strategic Defense Initiative Organization, and NASA is developing advanced technologies for a new generation of aerospace vehicles. After a horizontal take-off, these liquid-hydrogen fueled, airbreathing, ramjet/scramjet-powered vehicles will be capable of operating at hypersonic speeds (Mach 6 to 12) in the atmosphere or in space as a single-stage-to-orbit launch vehicle.

Between 1986 and 1989, the main goal of the technology development phase (Phase II) is development and proof-of-concept test of an integrated airframe/propulsion system capable of operating efficiently from takeoff to



Model of the National Aero-Space Plane.

orbit. New technologies needed to usher in this new generation of airbreathing aerospace vehicles will be developed, such as advanced propulsion engines, advanced low-drag airframe configurations, advanced high-temperature materials, actively cooled structures, lightweight cryogenic tankage, and computer fluid dynamics techniques. These technologies being developed offer the potential of a future space launcher having substantially reduced costs per pound delivered to orbit, and a future hypersonic cruise aircraft having two-hour flight time (or less) from the United States to any point on the globe.

The next phase (Phase III), the detail de-

sign, construction, and flight test of an experimental aircraft, will begin in 1989. First flight of this experimental vehicle, designated the X-30, is planned for 1993. The goal of Phase III is to accomplish sufficient flight demonstration to provide a verified technological basis for future operational vehicles.

The many spinoffs from NASP technologies will enhance U.S. leadership in aeronautics and in the commercial use of space during the early decades of the next century. Reduced space launch costs and dramatically reduced transit times on long-haul airline routes will result in significant economic benefits.

X-Wing. The X-Wing rotor system will be flight-tested on the NASA/Army Rotor Systems Research Aircraft (RSRA). Successful testing of the X-Wing/RSRA will provide the basis for a whole new generation of air vehicles that combine the best features of both helicopter and fixed-wing aircraft. In the helicopter mode, the X-Wing rotates like conventional helicopter blades. While airborne, the blades stop rotating and the aircraft will fly in a fixed-wing mode. In order to accomplish this feat, four emerging technologies will be refined and integrated: digital flight controls that can maneuver an airframe with both helicopter and fixed-wing features; composite materials that are both lightweight and extremely rigid; air that circulates around the rotor blades to increase lift; and propulsion techniques that provide both shaft horse power and thrust from a single engine.

During 1986, the X-Wing/RSRA was delivered to the Dryden Flight Test Center for final assembly under NASA supervision. This facility ensures safety by conducting several hours of operational testing to uncover component degradation that might affect flight tests. A second facility at NASA's Ames Research Center, which contains a manned simulator to explore the handling qualities of the X-Wing/RSRA, is being used for pilot training and flight readiness review.

Army Aeronautical Technology Research. The purpose of this program is to increase operational effectiveness of helicopters, reduce life cycle costs, and improve systems integration analysis and flight simulation capabilities. The program includes research in the areas of aerodynamics, structures, propulsion, reliability, maintainability, safety and survivability, subsystems, mission support, flight simulation, and man-machine integration. In 1986, research projects

undertaken or completed are as follows:

- A 15:1 centrifugal compressor test for Army aircraft power plants was successfully completed, demonstrating that program development goals were exceeded for compressor efficiencies and surge margin. If this new compressor is placed in a new Army aircraft engine, it will mean significant improvements in power plant efficiency and reductions in complexity.

- In laboratory testing, a high-speed (greater than 30,000 RPM) aircraft transmission clutch concept was validated that can significantly reduce clutch weight and improve capability and reliability.

- Aircraft structures testing was completed that included tests of a new crashworthy, cyclic flight control stick and UH-60 Blackhawk helicopter floor armor.

- Aircraft Combat Maintenance/Battle Damage Repair design guides were completed for Army aircraft fluid lines (fuel, hydraulic fluid, and oil) and for mechanical flight control components.

- Four computer simulations were conducted to support advanced Army rotorcraft: Light Helicopter Family (LHX) Flight Control System; single crew member advanced cockpit engineering to support the LHX program; roll control effectiveness evaluations; and UH-60 Blackhawk helicopter validations to support aircraft accident investigations.

Advanced Digital Optical Control System (ADOCS). The task of the Advanced Digital Optical Control System is to advance technology to provide a battlefield-compatible flight control system for new Army aircraft. The ADOCS will allow survivability of the control system in the natural and man-made electromagnetic environment of the future battlefield. The ADOCS also will provide improved capability, reliability, maintainability, and reduced ballistic vulnerability. Mission-tailored handling qualities combined with improved soldier-machine interfaces will significantly improve rotorcraft mission performance. A ground test of the ADOCS, using a UH-60 flight demonstrator, was completed and flight tests were initiated. The development of an Optohydraulic Servovalve was completed and work on a number of additional improved optical components was initiated. These components will be designed to upgrade and replace large, heavy, inefficient prototype components in the original flight demonstrator. The testing of the

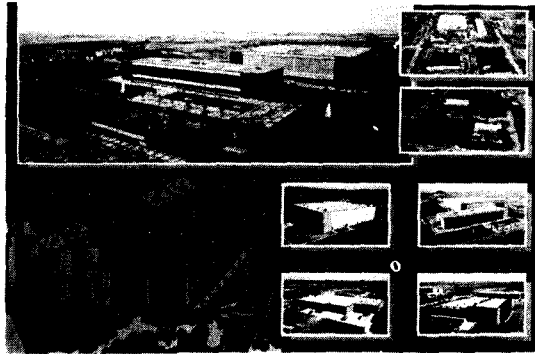
ADOCS Flight Demonstrator configuration was completed in 1986. Development of advanced optical components will continue, along with a Tri-Service program to develop approaches to Atmospheric Electrical Hazard Protection for the Digital Optical Control System.

Advanced Composite Aircraft Program (ACAP). ACAP was formulated to demonstrate the benefits of applying composite materials to a primary helicopter airframe structure. The program goals of achieving a 17-percent reduction in airframe cost and a 22-percent reduction in airframe weight were met or exceeded by the two helicopter manufacturers conducting this demonstration. In 1986, Sikorsky and Bell completed their ACAP flight test programs. The program then proceeded to the initiation of the militarization phase in which avionics/lightning compatibility issues will be addressed; landing gear and crashworthy characteristics will be demonstrated; and acoustics and maintainability improvements will be developed to ensure battlefield sustainability of composite materials used as a primary airframe structure. Due to the inherent high stiffness of composite materials, acoustic energy (noise) may be more readily transmitted than it is in metal structures. Acoustic isolation modifications for the ACAP aircraft will be fabricated and installed in the flight test vehicle; tests of the avionics, electromagnetic interference, and lightning characteristics of the airframe will be completed; and a concept for enhancing maintainability will be developed.

Low Speed Data Modem. In 1986, a contract was awarded to the Harris Corporation to fabricate two low-data-rate (75 bits per second) robust brassboard modems. The units will employ Harris serial modem technology and a computer-based message system that will provide "connect messages" and electronically synthesized voice to transmit commands, flight status, other Command and Control (C2) information, and targeting information to and from Army aircraft. Because of the robust signal processing nature of the units, a very reliable data communication link will be established. The technology will be studied and may become an integral part of the advanced communication prototype system.

Space and Aeronautics Support

Consolidated Space Operations Center (CSOC). CSOC was originally planned to consist of a Satellite Operations Complex (SOC) and a Shuttle Operations and Planning Complex (SOPC). The SOC will share the satellite



Consolidated Space Operations Center, Falcon Air Force Station, Colorado.

control work load with the Satellite Test Center (STC), and the SOPC would have provided facilities for secure flight planning and flight control for DoD Shuttle flights in conjunction with NASA's Johnson Space Center. Reduced DoD dependence on the Space Shuttle, a key aspect of the space launch recovery plan, coupled with budgetary constraints, caused the Air Force to cancel the SOPC portion of the CSOC development. Despite this cancellation, the CSOC/SOC will augment present control capacities and will strengthen U.S. space posture by eliminating vulnerabilities in the existing satellite control architecture.

Construction of CSOC's building, near Colorado Springs, Colorado, was completed in 1985. The Global Positioning System Master Control Station, a tenant at CSOC, began satellite operations in January 1986. The first of the CSOC's two Satellite Mission Control Centers will be activated in 1987, followed by the second in 1988. As described above, due to reduced Shuttle planning requirements and fiscal constraints, SOPC funding has been deleted from the CSOC program beginning in fiscal year 1988.

U.S. Army Space Agency (USASA). The USASA was provisionally activated in August 1986, at Colorado Springs, Colorado, as the Army component of the U.S. Space Command (USSPACECOM). The unit is a field operating agency of the Office of the Deputy Chief of Staff for Operations and Plans,

HQDA, and is under operational command of USCINCSpace. By the time of its formal activation in October 1987, the agency will consist of 35 personnel and two detachments. One detachment, stationed at Falcon AFS, Colorado, will conduct satellite control operations; the other, located at Johnson Space Center (JSC), Houston, Texas, will consist of Army astronauts and other Army personnel assigned to JSC. As Army space operational requirements evolve, USASA will command forces developed to meet those requirements. Currently, the USASA provides USSPACECOM an Army perspective in planning DoD space system support for land forces and for strategic defense. The agency also will ensure integration of Army requirements into USSPACECOM planning and operations, and respond to needs of USCINCSpace, such as providing operational forces, as appropriate.

As part of the Army's organization for space, the Army Training and Doctrine Command (TRADOC) activated the Army Space Institute (USASI) in June 1986, at Fort Leavenworth, Kansas, to represent Army interests in the process of defining military space requirements. The USASI represents the Army user community in developing and integrating space-related concepts and doctrine across all Army mission areas; it is the Army's proponent for space-related doctrine development, combat development, training support, and personnel functions; and it is integrative in nature, and is subordinate to TRADOC's Combat Arms Development Activity.

Eastern Space and Missile Center (ESMC). ESMC, at Patrick Air Force Base, Florida, provides developmental and operational launch services for the Army's Pershing missile, the Navy's Poseidon and Trident missiles, and the Air Force's short-range attack missiles. It also supplies launch and support services for NASA and DoD satellites, and continuous tracking of space objects. In 1986, ESMC supported 17 ballistic missile tests, four major space test operations, and one Space Shuttle launch.

Western Space and Missile Center (WSMC). WSMC, at Vandenberg Air Force Base, California, provides developmental and operational launch services for the Air Force's Minuteman and Peacekeeper missiles, space vehicles of NASA and DoD that require polar orbits, and tracking and data acquisition support for aeronautical tests of the B-1 and

cruise missiles. In 1986, WSMC supported 4 major space launches and 14 ballistic missile launches.

White Sands Missile Range (WSMR). In 1986, WSMR provided developmental and operational launch and testing services for a variety of DoD and NASA systems. Launch, flight, and recovery services included ground and flight safety, range surveillance, command and control activities, and associated data acquisition and analysis for numerous short- to medium-range surface-to-surface, surface-to-air, and air-to-surface missiles and rockets of the Army, Navy, Air Force, and commercial users. Nonflight hardware testing was conducted on these same systems, on the Peacekeeper/Minuteman and Small ICBM, and on the Shuttle orbiter and launch systems. Other activities included upper atmospheric soundings using rockets and balloons, a variety of astronomical test programs, precision aircraft positioning and tracking, and tests involving both ground- and space-based laser and directed energy systems. Shuttle-related activities included operation of the ground terminal of the Tracking and Data Relay Satellite system, and Shuttle flight and landing support.

U.S. Army Kwajalein Atoll (USAKA). Systems and projects supported at USAKA in 1986 included Minuteman and Peacekeeper testing, and the SDI's Delta 180 twin-satellite space mission. Implementation of the Compact of Free Association between the United States and the Republic of the Marshall Islands ensures that USAKA will continue to be available to support the requirements of the SDI and the developmental and operational testing of U.S. strategic offensive missiles. USAKA is one of two DoD ranges agreed to in the ABM Treaty for ballistic missile defense testing. USAKA has unique capabilities for collecting signature data on objects in space, recording missile reentry phenomena, providing terminal trajectory and impact data, and recovering reentry vehicles.

Armament Division (AD). The AD, at Eglin Air Force Base, Florida, conducts research, engineering development, test evaluation, and initial acquisition of Air Force non-nuclear munitions. It operates 43 aircraft, and uses 50 instrumented test ranges covering 724 square miles of land, and 86,500 square miles of water, extending nearly 240 miles south into the Gulf of Mexico. In 1986, AD tested the Advanced Medium Range Air-

to-Air Missile, the Airborne Self Protection Jammer, IR Maverick AGM-130 Munition, and the Joint Tactical Information Distribution System.

Arnold Engineering Development Center (AEDC). The AEDC, at Arnold Air Force Station, Tennessee, conducts engineering development tests for both Government and commercial users. In 1986, programs it supported included Peacekeeper, Space Shuttle, Small Intercontinental Ballistic Missile, Advanced Tactical Fighter, Strategic Defense Initiative, and Short Takeoff and Landing fighter technology.

Air Force Flight Test Center (AFFTC). AFFTC, at Edwards Air Force Base, California, is an ideal test area with a large air space, dry lake beds, isolation, and highly instrumented ranges. This unique facility provides support for many users, including NASA's Dryden Flight Research Facility, the Army Aviation Engineering Flight Activity, and the Air Force Rocket Propulsion Laboratory. In 1986, the Center supported tactical and strategic systems activities such as the B-1B, F-15, F-16, F-20, X-29, B-52 avionics modifications, C-17 parachutes and load extraction systems, advanced fighter technology integration, and air- and ground-launched cruise missiles.

4950th Test Wing. The 4950th Test Wing, based at Wright-Patterson Air Force Base, Ohio, tests military systems, subsystems, and components for the Air Force Systems Command (AFSC). In 1986, the 4950th Test Wing, continued support to DoD and NASA with the Advanced Range-Instrumentation Aircraft, which serves key telemetry, data processing, and command control functions during aeronautical flight testing and space missions.

6585th Test Group. The 6585th Test Group is located at Holloman Air Force Base, New Mexico, and is responsible for operation of the Central Inertial Guidance Test Facility, the Radar Target Scatter Facility, and the High Speed Test Track. These facilities support inertial navigation system training, high-speed sled track simulations, and antenna and radar cross section measurements. In 1986, programs supported included the B-B1, Trident, Small Intercontinental Ballistic Missile, Advanced Medium Range Air-to-Air Missiles, and Crew Escape Systems Technology. The Test Group is also the airspace manager for the White Sands Missile Range.

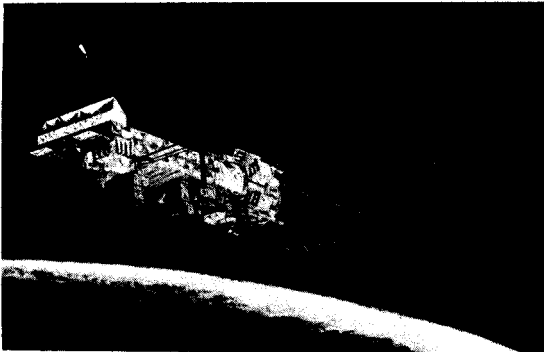
Relations with NASA

National Space Transportation and Support Study. DoD participated in a joint study with NASA on next-generation space transportation requirements, architecture, and technology. Study results, which were reported in May 1986, and provided to the National Security Council, show that a mixed fleet, consisting of a new cargo and manned launch vehicles, will be required to meet the Nation's civil and national security space transportation needs of the late 1990's and early 21st century. The study results are being used to direct technology programs that will allow next-generation space transportation systems to be much more cost effective than current systems.

Department of Commerce

Three agencies of the Department of Commerce—the National Oceanic and Atmospheric Administration, the National Bureau of Standards, and the National Telecommunications and Information Administration—made contributions to U.S. aeronautics and space programs in 1986.

The National Oceanic and Atmospheric Administration (NOAA) continued its operation of the TIROS/NOAA and GOES families of environmental satellites. NOAA uses these spacecraft to sense and collect data about conditions in the atmosphere, oceans, near-space, and on land. It transmits the data, in raw and processed form, to the user community, which applies them to operational and research use. This community consists of national and international participants, including the U.S. military. The most notable uses of NOAA satellite observations are for forecasting weather and issuing storm or natural disaster warnings. The TIROS/NOAA and GOES satellites are operated by NOAA's National Environmental Satellite, Data, and Information Service, which also archives



TIROS/NOAA spacecraft.

the data obtained from spacecraft observations. Data and satellite-derived products and services are distributed by NOAA's National Weather Service, National Ocean Service, and National Marine Fisheries Service. In addition, the information provided by the satellites is used by NOAA's Oceanic and Atmospheric Research Laboratories to develop a better understanding of the composition and processes of the Earth's air, sea, and land environment.

The primary role of the National Bureau of Standards (NBS) in space is to support fundamental research and testing in aerospace technology, particularly in the areas of materials and processes.

As the worldwide demand for frequencies in the radio spectrum increases, effective allocation and management of this limited resource are essential. The role of the National Telecommunications and Information Administration (NTIA) is to help develop and coordinate U.S. policy in space communications.

Space Systems

Satellite Operations

The satellites operated by NOAA include both polar-orbiting and geostationary spacecraft. Each of the two polar-orbiting satellites, interchangeably called TIROS and NOAA, move in circular, Sun-synchronous orbits 450 nautical miles above the Earth's surface and are inclined 98.7 degrees to the Equator. Since the spacecraft orbit the Earth at the same rate as the Earth moves about the Sun, the time of day that they view the Earth does not change. Each of the two satellites that comprise the TIROS/NOAA system views every point on the globe at least twice daily, once in daylight, and once at night.

The polar-orbiting satellites observe the Earth in the visible and infrared portions of the electromagnetic spectrum by means of an Advanced Very High Resolution Radiometer (AVHRR) that provides images of cloud cover, surface water, land masses, snow and ice, and measures surface temperatures. A TIROS Operational Vertical Sounder (TOVS) senses radiant energy from the atmosphere to determine water vapor content and construct a temperature profile from the surface to the upper stratosphere; a Space Environment Monitor (SEM) measures energetic particles at orbital altitude; and an ARGOS Data Collection and Platform Location System (DC-PLS), provided by France, collects and relays information from environment-sensing platforms, such as buoys and balloons, and provides the data to track them. The Search and

Rescue System (SAR) receives and retransmits messages sent by persons in distress through Emergency Locator Transmitters and Emergency Position-Indicating Radio Beacons. These retransmissions are used in the dispatch of search and rescue parties.

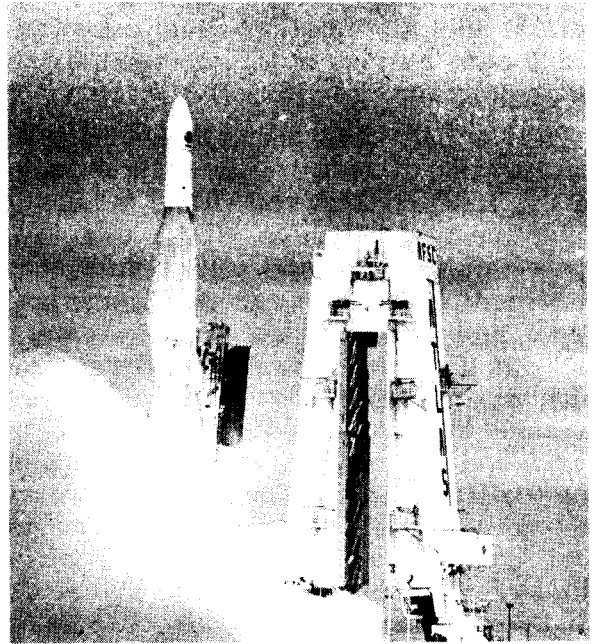
In addition to recording and storing data for NOAA's Command and Data Acquisition Stations located at Wallops, Virginia, and Fairbanks, Alaska, TIROS/NOAA spacecraft provide continuous broadcast services for domestic and foreign stations. High and low resolution AVHRR imagery, and TOVS sounding data are broadcast. They are known as High Resolution Picture Transmission, Automatic Picture Transmission, and Direct Sounder Broadcast services.

With respect to the surface of the Earth, the Geostationary Operational Environmental Satellite (GOES), remains stationary. At an orbital altitude of 19,300 miles, its rate of angular movement around the Earth equals that of the Earth's rotation. Consequently, its observing position over the Equator remains fixed and the spacecraft maintains an uninterrupted view of the Earth. Sensing by the Visible and Infrared Spin-Scan Radiometer Atmospheric Sounder (VAS) on the spacecraft provides day and night images of the Earth, and allows the development of atmospheric temperature profiles and maps of water vapor. In addition, GOES carries a Space Environment Monitor (SEM) that reports on the condition of the Earth's magnetic field and the energetic particle flux at its geostationary altitude; and a Data Collection System (DCS) that relays the data sensed in-situ by environmental reporting platforms. Unlike polar-orbiting spacecraft, the GOES has no platform-locating capability. Because some of the platforms must be interrogated, an interrogation signal is broadcast that includes precise National Bureau of Standards time. Also, GOES serves as a means to broadcast processed environmental data, such as imagery, charts, and alpha-numerics through a product distribution technique called Weather Facsimile (WEFAX).

The normal operational configuration for the GOES system includes one spacecraft placed at 75 degrees west and one at 135 degrees west. From these locations they can observe the eastern and western parts of the United States and their adjacent ocean areas. Other GOES satellites, used for communications relay, may be positioned elsewhere.

Polar-Orbiting Satellites. NOAA 6 and

NOAA 9 provided the agency's polar-orbiting service for most of the year. Originally launched in 1979, NOAA 6 was reactivated and returned to service, replacing NOAA 8 when it became unusable. Although NOAA 6 operated without part of its vertical sounding system and tape recorders, it was able to function until a new spacecraft, NOAA 10,



Launch of the NOAA 10 satellite from Vandenberg Air Force Base on September 17, 1986.

could be placed in orbit. This was accomplished in a near perfect launch from Vandenberg Air Force Base on September 17, 1986. NOAA 10 became operational on November 19, 1986.

Geostationary Satellites. As the only GOES satellite that was fully operational at the beginning of the year, GOES 6 continued to provide imaging and sounding data throughout 1986. In a "one-GOES operating mode," it was positioned above 98 degrees west to supply coverage for the summer/fall hurricane season. From its alternate winter/spring position at 108 degrees west, maximum coverage of winter weather from the Pacific Ocean and Gulf of Alaska was achieved. WEFAX, DCS, and SEM services were provided using the standby satellites, GOES 2, 3, 4, and 5, which no longer had imaging capability.

In early May 1986, an attempt was made to launch a new GOES satellite, GOES G, that would have reinstated a full two-GOES system. The effort resulted in failure when the



GOES spacecraft.

main engine of the Delta launch vehicle shut down prematurely; subsequently, the GOES G satellite had to be destroyed. GOES H, the last of the current series of GOES spacecraft, is scheduled for launch in February 1987.

GOES-Next. During 1986, the Ford Aerospace and Communications Corporation pursued the design and development of the next-generation GOES spacecraft, GOES I-M, and associated ground equipment. Launch of the first in the new series of spacecraft is expected in 1989.

LANDSAT Commercialized Operations. Pursuant to the Land Remote Sensing Commercialization Act of 1984, the Earth Observation Satellite Company (EOSAT) operated the Landsat land remote sensing satellite system for NOAA in 1986. Construction of the next-generation Landsat 6 satellite has been halted pending Congressional approval of an Administration funding plan required under the FY 1987 Continuing Resolution. Once approved, new sensor packages will be developed that include the Enhanced Thematic Mapper, featuring a 15-meter resolution panchromatic band, and other spectral bands, including thermal infrared; and a Wide Field Sensor that will provide low resolution, wide area coverage suitable for land and ocean studies.



Artist's conception of a "GOES-Next" satellite.

EOSAT has begun to develop a satellite receiving center in Norman, Oklahoma and an operations and control center in Princeton, New Jersey to be used for ground data capture, processing, and flight control for Landsat 6.

Satellite Data Services

During 1986, NOAA provided the following satellite data services made possible by the observing and communicating capabilities of TIROS/NOAA and GOES spacecraft:

GOES Data Collection System (DCS). In 1986, the System had an increase of over 2,000 environment-sensing data collection platform assignments. DCS buoy, aircraft, river gauge, and other data were distributed to 69 national and 30 international users which included 25 direct readout stations (20 domestic and 5 non-U.S.). The second edition of the GOES DCS Users Catalog was completed and distributed, and contains the data collected, user identification, and addresses of all platforms operating within the System.

WEFAX. Using three GOES spacecraft, the Weather Facsimile (WEFAX) service broad-

cast processed satellite imagery, meteorological analyses and prognoses, operational messages, and satellite ephemeris bulletins. The number of known WEFAX users increased to 220 (107 domestic and 113 non-U.S.).

Navy/NOAA Joint Ice Center. In April 1986, a Letter of Agreement was signed between the Navy and NOAA to improve data processing capabilities at the Navy/NOAA Joint Ice Center in Suitland, Maryland. The acquisition and installation of a digital image processing system at the Center will allow significantly enhanced operational ice data analyses and predictions for both the military and civil communities.

GOES-VISSR Atmospheric Sounder (VAS) Data. In mid-June 1986, a VAS Data Utilization Center was delivered to the National Environmental Satellite, Data, and Information Service to evaluate its usefulness in applying GOES VAS data to monitor tropical storms, severe weather outbreaks, and major winter storms. Evaluation results were extremely favorable, and three additional Centers have been proposed to support the National Meteorological, National Severe Storms, and National Hurricane Centers.

Atmospheric Temperature and Moisture Sounding. The year 1986 marked the seventh year of atmospheric soundings produced through NOAA's polar-orbiting satellite system. In April, a major improvement was made with the implementation of the TIROS Operational Vertical Sounder (TOVS) Enhancement Sounding System. The System produces soundings at a higher horizontal resolution in meteorologically active areas, and provides additional temperature and moisture data where they are most needed. The increase in resolution was accomplished without compromising data accuracy. Processing efficiency was improved with new computer facilities that allow soundings to be provided to the user community within 1 hour and 20 minutes of satellite data read-out.

Sea Surface Temperatures. Observations of sea surface temperatures, made at 8 kilometer resolution, are produced from polar-orbiting satellite infrared data and transmitted to the National Meteorological Center of the National Weather Service, the Navy Fleet Numerical Oceanography Center, and the World Meteorological Organization for use in oceanographic and meteorological products. A variety of sea surface tempera-

ture analyses were added to charts that cover U.S. coastal waters, and are being used by forecast offices of the National Weather Service. In August 1986, the creation of a new archive on sea surface temperature observations was initiated for the Tropical Ocean and Global Atmosphere (TAGO) project of the World Climate Research Program.

Satellite Weather Information System (SWIS). The National Weather Service completed development of the Satellite Weather Information System (SWIS) which will provide sophisticated capabilities for display and animation of GOES imagery at all forecast offices and national centers. In early 1987, SWIS will be integrated with the Automation of Field Operations and Services system at field sites, and will allow simultaneous display of GOES imagery and numerical guidance products, such as charts, that are generated from the National Meteorological Center. Animation of GOES images and superposition of guidance products will improve the ability of forecasters to monitor guidance material and track severe weather.

Search and Rescue. In 1986, the international satellite search and rescue service provided by Canada, France, the United States, and the Soviet Union was responsible for the rescue of 178 people, for a total of about 700 people, to date. In January 1986, a prototype user awareness program to reduce the 99 percent false alarm rate for the 121.5 MHz frequency was initiated in Alaska. In August, a similar program began in California; the governor proclaimed a false alarm awareness day, and a legislative resolution was introduced proclaiming 1987 as the year of air and maritime safety.

In January 1986, the Maritime Safety Committee of the International Maritime Organization (IMO) approved 406 MHz as the primary frequency for the float-free emergency position indicating radio beacons for the future global maritime distress and safety system.

Fisheries. Based on Coastal Zone Color Scanner information obtained by NASA's Nimbus 7 satellite, experimental charts of the eastern Pacific Ocean and the Gulf of Mexico were prepared showing the location of weather mass boundaries that are useful in locating potentially productive fishing areas. With this information, it was estimated that the Gulf commercial fishing fleet could save 20 percent of its time and expense in longline fishing operations. Creation of the charts,

made at the request of the fishing industry, was a joint project of the National Marine Fisheries Service, National Ocean Service, Scripps Institute of Oceanography, and Goddard Space Flight Center.

Space Environment Services. NOAA's Space Environment Services Center prepares a weekly summary of variations in the space environment that includes solar activity and its effects on the terrestrial environment. In 1986, a set of plots describing conditions in the geostationary environment that may be deleterious to spacecraft was added to its data base.

Training. During 1986, NOAA's commitment to training in the applications of satellite imagery increased. A major effort was initiated to ensure coordinated interagency satellite training with films, laboratory exercises, audio cassettes, and tape-slide programs. The Satellite Applications Laboratory of the National Environmental Satellite, Data, and Information Service (NESDIS) began conducting two training courses annually for U.S. Navy officers. In addition, training was provided to National Weather Service and Air Force forecasters, and to Navy reservists. In 1986, approximately 1,000 persons received satellite applications training from NOAA.

The National Weather Service and NESDIS jointly developed a training program on satellite imagery interpretation, emphasizing imagery animation. The program's two components consist of a handbook on imagery interpretation, and a collection of videotapes depicting various aspects of imagery analysis. The handbook entitled "NWS Forecasting Handbook #6, Satellite Imagery Interpretation for Forecasters" is a collection of 54 papers divided into eight chapters. Each chapter covers a unique meteorological phenomenon ranging from basic interpretation and synoptic scale analysis to convection and fog stratus. The collection of four twenty-minute videotapes covers topics on basic cloud identification, tropical upper-air vortex motion, fog and stratus identification, and absolute/relative cloud motions. Distributed in the summer of 1986, the tapes supplement two other tapes that depict the initiation of convection and thunderstorm outflow boundaries from the satellite perspective. Other tapes, covering both synoptic and mesoscale frontal analysis, will be developed and distributed in early 1987.

Stereo Physiographic Map of the World.

Techniques used for processing satellite imagery were used to create and interpret a stereo-physiographic map of the world. Digital elevations and bathymetry data archived at NOAA's National Geophysical Data Center were processed to create the map, which was presented at the annual meeting of the Geological Society of America. The map gives scientists a unique perspective of the Earth's physiography and is useful in interpreting global-scale features that may improve understanding of the Earth's geological processes.

International Activities

World Administrative Radio Conferences. World Administrative Radio Conferences (WARC's) are conducted under the aegis of the International Telecommunication Union (ITU), and the National Telecommunications and Information Administration (NTIA) of the Department of Commerce actively participates in them. The NTIA prepared for the 1987 Mobile WARC and the 1988 ORB(2) WARC, both of which will be of major importance to U.S. space interests.

Proposed changes to the ITU Radio Regulations that were proposed at the 1987 Mobile WARC include allocation of 1500/1600 MHz to the Radio Determination Satellite Service (RDSS) and Mobile Satellite Service (MSS). The RDSS would use satellites to provide users with specific information on their location for management, inventory, and safety. The MSS allocation would accommodate land mobile, aeronautical mobile, and maritime mobile services. The WARC on the Use of the Geostationary Satellite Orbit and the Planning of Space Services Utilizing It, commonly known as the ORB(2) WARC, will address the critical issue of equitable access to the geostationary orbit for all countries.

Advanced Communication Technology Satellite Experimentation. Planning continued for experiments that NTIA will conduct using the Advanced Communications Technology Satellite (ACTS) under development by NASA. Experiments projected include network and switching performance measurements, system performance measurements, utilizing the user-oriented performance parameters recommended by American National Standard X3.102-1983, beam-pointing, timing accuracy measurements,

and propagation studies. Results of these experiments are expected to provide information important to future satellite communications systems.

Assistance to the Egyptian Government. NOAA's National Geophysical Data Center (NGDC) provided technical assistance to the Minerals, Petroleum and Groundwater Assessment Program of the Egyptian Government, an effort sponsored by the U.S. Agency for International Development. NGDC assisted in processing and interpreting satellite imagery, and integrating satellite images with geophysical data for resource exploration and assessment.

CGMS. In November 1986, the Coordination of Geostationary Meteorological Satellites (CGMS) group, consisting of representatives from the United States, Japan, India, the Soviet Union, and the European Meteorological Satellite (EUMETSAT) community, met in New Delhi, India. Included in its agenda were issues such as relaying Indian satellite imagery data to the United States; planning for contingencies where one satellite replaces another; changing the schedule for Data Collection System (DCS) platform-reporting; and refining satellite-borne calibration techniques.

ARGOS. In 1986, the Centre National d'Etudes Spatiales (CNES) created a subsidiary organization responsible for all promotional and operational activities of the ARGOS system. In the spring of 1987, a CNES ARGOS data processing center will become operational in the Washington, D.C., area.

International Training. In 1986, visiting foreign scientists were trained by NOAA in applications of remote sensing data obtained by environmental satellites that included estimating precipitation from satellite imagery, assessing climate, forecasting weather and crops, and managing satellite data.

Research

Technology for Space Flight. In 1986, research resources of the National Bureau of Standards were applied to a variety of space flight-related subjects:

Studies on fluid-fluid and fluid-solid interfaces were conducted as prototype experiments for low gravity research in an orbiting laboratory. The feasibility of using low grav-

ity space environments to measure very high temperature thermophysical properties of liquids and solids was explored. Heat transfer analyses made on the behavior of liquid oxygen and liquid hydrogen in a low gravity environment, similar to that experienced by the Space Shuttle, have implications for future experiments that will be conducted on the Space Station.

In the area of materials science, NBS provided consultation to aerospace companies on the feasibility of fabricating a liquid hydrogen or slush hydrogen fuel tank from all-graphite epoxy composites for the proposed Aero-Space Plane. In an effort to find safer components for launch vehicles and ground-based support systems, NBS also studied the ignition and combustion characteristics of metals that come into contact with high pressure oxygen.

Using funding supplied by INTELSAT, NBS made a comparative evaluation of measurement techniques that could be used to determine the performance of antennas on the new INTELSAT VI spacecraft. The objective of the evaluation was to find the measurement technique best suited for such a complex system. When completed, the evaluation will benefit measurement support for all emerging high-performance satellites.

Detection of Gravitational Waves. Scientists at NBS assessed the practicality of using a laser, on an experimental basis, to detect gravitational waves in space that last about 0.1 seconds or longer. The detection of such waves or pulses by means of a laser would provide an entirely new way to study events in the universe that involve very large masses. These events include collisions of massive black holes, thought to exist at the center of many galaxies, that probably provide the energy source for quasars.

Earth's Atmospheric Chemistry. Through a cooperative agreement with NASA, NBS engaged in experiments on the chemical dynamics of gas phase processes (reaction rates and mechanisms) selected for their importance to the study of atmospheric chemistry. The results of these experiments are expected to assist in modeling various atmospheric phenomena, such as the effects of natural and atmospheric emissions on the stratospheric ozone layer, atmospheric radiation budget (greenhouse effect), and tropospheric acid precipitation.

Planetary Atmospheres. In a program spon-

sored by NASA, in collaboration with several universities, NBS investigated far infrared absorption spectra that result from collisions of nonpolar molecules found in the atmospheres of the outer planets. The investigation is expected to lead to a better understanding of the nature of thermal emissions from these atmospheres, the amount of gases such as hydrogen, helium, methane, and nitrogen, and to determine temperature profiles.

Satellite Magnetometer. To determine the practicality of various designs for the Geomagnetic Autonomous Shuttle-Launched Probe (GASP), a three-phase study was conducted for the Navy by NOAA's National Geophysical Data Center. GASP will serve as the survey platform for the Naval Oceanographic Office's Project MAGNET. The study investigated cheaper and simpler ways to survey the geomagnetic field by satellite.

The COHMEX Experiment. In the summer of 1986, the Cooperative Huntsville Mesoscale Experiment (COHMEX) was conducted to provide a better understanding of thunderstorms and their associated downbursts. It was supported by GOES and TIROS/NOAA spacecraft, Doppler radars, NOAA special rawinsonde coverage, the Federal Aviation Administration, aircraft flights sponsored by the National Science Foundation, and special Tennessee Valley Authority rain gauge and surface reports. The experiment included studies of microbursts and severe thunderstorms in a moist environment; downburst influence on aircraft performance; mesoscale environments as they affect precipitating storm development and evolution; and arc cloud lines to understand thunderstorm outflow dynamics and how outflow interacts with local environments to influence deep convective storms.

Satellite Cloud Climatology. In a program that compiles a global data set of calibrated visible and infrared radiances, the Satellite Research Laboratory of NOAA's National Environmental Satellite, Data, and Information Service collected data from international geostationary and polar-orbiting satellites. The radiances will be processed into a cloud data set that includes cloud top temperatures, volumes, heights, and optical thickness, helpful information to understand the role of clouds in the Earth's radiation budget and hydrological cycle.

Hurricane Research. In its 1986 hurricane field program, the Hurricane Research Divi-

sion of NOAA's National Hurricane Center used the communications capability of the GOES Data Collection System. Atmospheric sounding data from the mid- and lower-troposphere were transmitted by dropwindsondes to a NOAA aircraft and, subsequently, relayed by an aircraft-to-GOES data link. Also, the TIROS/NOAA spacecraft provided support by relaying data from drifting buoys.

Aeronautical Programs

Charting. As part of its continuing responsibility to produce charts, NOAA's National Ocean Service developed a Pacific Oceanic Route Chart, for use by Federal Aviation Administration air traffic controllers, and a Navigational Aid Digital Data File that contains the geographic position, type, and unique characteristics of every navigational aid in the United States, Puerto Rico, and the Virgin Islands.

Department of Energy

The U.S. Department of Energy (DOE) and predecessor agencies, (the Atomic Energy Commission, and the Energy Research and Development Administration) have supported efforts to design, develop, produce, and deliver Radioisotope Thermoelectric Generators (RTG's) for highly specialized space and terrestrial applications. In fact, 1986 marked the 25th anniversary of the first use of RTG's, previously referred to as Systems for Nuclear Auxiliary Power (SNAP). Over this time, the RTG's delivered by DOE to the National Aeronautics and Space Administration (NASA), and to the Department of Defense (DOD) provided safe and highly reliable electrical power sources that contributed to the success of some of the most ambitious and spectacular astronomical events ever undertaken by the United States. The five SNAP-27 RTG's, launched between 1969 and 1972, to power the Apollo lunar experimental packages, were still operational when the lunar stations were closed in September 1977. The SNAP-19 RTG's, launched in 1975 on the Viking Lander, allowed an extended mission on the surface of Mars. The SNAP-19 RTG's, launched in 1972 and 1973 on the Pioneer 10 and 11 missions to Jupiter, are still operational. Pioneer 11 has flown past both Jupiter and Saturn, and Pioneer 10 has passed the orbit of Pluto, the outermost planet. The MultiHundred-Watt (MHW) RTG's, launched in 1977 on the Voyager 1 and 2 spacecraft, are still operational. This has allowed NASA to complete long-duration flights to Jupiter and Saturn; and in 1986, Voyager 2 made a spectacular flyby of Uranus. Voyager 1 is now headed for Neptune.

Space Nuclear Power Systems

Space nuclear power systems are of two basic types: reactors or isotopic, and are generally categorized by the type of energy conversion systems used, either static or dynamic. The RTG is a static isotopic power system that consists of a radioisotope heat source thermally coupled to a converter segment; it is not dependent on moving parts to

generate electricity. Thermoelectric elements in the converter section convert heat, generated by decay of the radioisotope, to electricity by means of a basic material property referred to as the Seebeck effect. Plutonium-238 fuel has been used to power all U.S. space RTG's launched to date.

The remarkable success of RTG's in space applications can be attributed to RTG technological advances that improved systems safety and efficiency, as reflected in enhanced specific power and increased power output. For example, mission power was increased from the SNAP-3A's 2.7 watts of electricity, used on the TRANSIT navigational satellite launched in 1961, to about 158 watts of electricity from the MHW-RTG's used on NASA's Voyager spacecraft launched in 1977. The specific power for these two systems increased from 1.29 to 4.2 watts of electricity per kilogram. This improvement was the result of enhanced design features, including the use of silicon-germanium (SiGe) thermoelectrics in the MHW-RTG, as opposed to the lead-tellurium technology used in the SNAP-3A. The use of SiGe thermoelectrics increased system efficiency to 6.6 percent, compared to 5.1 percent in the SNAP-3A; a fuel change from plutonium metal to pressed oxide contributed to system safety, and allowed RTG systems to operate at higher temperatures (approximately 1,000 degrees Centigrade), which yield higher specific powers. The successful performance of the MHW-RTG's resulted in the use of SiGe technology for the high power, 285 watts, General-Purpose Heat Source RTG (GPHS-RTG). The GPHS-RTG has a specific power of 5.2 watts of electricity per kilogram, compared to the MHW-RTG's 4.2 watts of electricity per kilogram. Four flight qualified GPHS-RTG's were fabricated and tested by DOE, and are available to support NASA's Galileo and Ulysses missions.

The improved designs of the RTG's have consistently demonstrated that they are dependable power supplies that are independent of the external environment. Designs, ranging from the SNAP-3A to the MHW-RTG, have provided power at or exceeding requirements. The MHW-RTG's have operated

five years beyond their projected lifetime, which was demonstrated in January 1986 by the Voyager 2 encounter with the distant planet Uranus. Similarly, improved design features are reflected in the construction of the newest GPHS-RTG's. A unique feature of the GPHS-RTG is that it is fueled with a modular heat source that improves safety and provides a higher specific power. The RTG has 18 fueled modules, each containing 250 thermal watts of plutonium-238 in the form of oxide pellets. DOE continues to support studies of RTG design, heat source materials, and thermoelectric materials to ensure optimum performance on future space missions, such as those using Mariner Mark II Class spacecraft.

In January 1986, four GPHS-RTG's (F-1, F-3, F-4, F-5), were sent to the Kennedy Space Center (KSC) to prepare for the Galileo and Ulysses space missions. However, due to the tragic accident of the Space Shuttle Challenger, they were not used as intended. Nevertheless, the RTG's were used at KSC to provide direct system integration data, such as matching the F-1 and F-5 RTG's to the Galileo spacecraft, and experiments were conducted using the F-3 RTG and the Ulysses spacecraft. Subsequently, the RTG's were returned to DOE's Mound Plant in Ohio for servicing, monitoring, and safekeeping until required by future missions. Under simulated space conditions, testing of the GPHS-RTG Qualification Unit, and the electrically heated Engineering Unit continued, and demonstrated power performance to design specifications. The LightWeight Radioisotope Heater Units, consisting of 134 units of approximately 1 watt each that will be used to keep instruments warm on the Galileo spacecraft, also were returned for storage at the Los Alamos National Laboratory.

Building upon the success of SiGe thermoelectric technology, DOE sponsored the development of a Modular RTG (MOD-RTG) that offers the potential of higher power per unit mass, based upon a modular concept compatible with the Mariner Mark II spacecraft. Also, work continued on development of a multicouple (a collection of thermoelectric elements bonded together), with emphasis placed upon improving the insulating glass that separates the thermoelectric elements.

SP-100 Space Reactor Program

The goal of the SP-100 Space Reactor program is to develop, and demonstrate the effec-

tiveness of space nuclear reactor technology that can provide up to about one megawatt of electric power for military and civilian space missions in the 1990's and beyond. Completed in 1985, Phase I of the program established technical and safety feasibility, and one power system concept was selected for further development and testing. Phase II activities, that will be conducted from 1986 through 1992, involve civilian and military mission analyses, defining requirements, developing and testing a prototype SP-100 space reactor power system, and pursuing advanced aerospace technology that could improve system capability in the future.

Under the Phase II agreement reached by DOE, DOD, and NASA, DOE is responsible for SP-100 Ground Engineering System (GES) development and testing; DOD's Strategic Defense Initiative Organization, using the Air Force as its executing agent, is responsible for military mission analyses and defining requirements; and NASA is responsible for civilian missions analyses and defining requirements, and investigating advanced aerospace technologies that could enhance an SP-100 power system in the future.

SP-100 Ground Engineering System (GES). In late 1986, contract negotiations for GES were initiated with contract selection expected in the fall of 1987. The contract package, which represents the largest and most important activity of the SP-100 Phase II program, contains extensive system definition requirements that must be met to satisfy program objectives.

During Phase II, a prototypical space reactor will be tested in a vacuum chamber, which simulates the space environment. Plans were made to modify facility designs, and to refine resource estimates to meet the GES schedule and test program objectives.

Technology Development. To continue high priority work on thermoelectric materials and cell fabrication, technology contracts were awarded to develop and characterize high temperature thermoelectric cell insulator materials that are thermally and chemically compatible with long-term operation; to synthesize thermoelectric materials, and develop thermal and electrical contact bonds; and to design, fabricate, and test compliant pads for the thermoelectric cells using state-of-the-art materials and production processes.

Testing continued on fuels and materials irradiation. Three fuel irradiation tests were

conducted in DOE's Experimental Breeder Reactor Number II (EBR II). To date, maximum burn up is 3.6 atom percent, which represents more than one-half the design life. Post-irradiation examination of the first two sets of fuel pin tests were completed, and the results agreed with predictions. Materials test specimens irradiated in EBR-II were removed from the reactor, and shipped to DOE's Hanford Engineering Development Laboratory (now Westinghouse Hanford Company) for examination and testing. Also, planning and design of the test capsule for prototype fuels and materials irradiation in DOE's Fast Flux Test Facility continued. Materials to produce fuel for the GES reactor test were installed. Hyperstoichiometric uranium nitride fuel pellets were fabricated in large batches, and analyzed at the Los Alamos National Laboratory.

Program Planning. Program planning activities underway include the development and implementation of an SP-100 Project Plan, a Project Management Plan, a Comprehensive Safety Program Plan, detailed Safety Implementation Plans for each participant, and a rigorous Quality and Reliability Program Plan. Plans also were finalized for the technical work to be performed by the participating federal laboratories, particularly in the areas of fuel and materials fabrication and testing, thermoelectric materials development and testing, and characterization of heat transport components.

Phase II activities will lead to Flight System Production, Qualification, and Application/Demonstration, the third and final phase of the SP-100 program, scheduled for 1992 through 1995. Included in Phase III is actual launch and first use of the technology in spaceflight.

Nuclear Test Detection

DOE continues to support the national requirement to verify compliance with the Limited Test Ban Treaty and the Nonproliferation Treaty by producing nuclear detonation detection systems deployed as secondary payloads aboard DOD satellites. These systems consist of optical and direct radiation sensors, and are the primary means of monitoring nuclear testing in the atmosphere. They are also the only systems capable of detecting nuclear detonations in space.

DOE laboratories, that produce the detection systems, maintain continuous programs to improve related technology. The goals are to obtain improved energy resolution, faster sensor response times, wider spectra coverage, compression of data processing, greater survivability, and development of new applications and sensors. Also, in order to enhance event discrimination and prevent false alarms, considerable research is devoted to the study of satellite operating environments. Many developmental experiments are flown aboard NASA satellites, and many are conducted jointly with other nations.

Department of the Interior

As the Nation's principal conservation agency, the Department of the Interior is responsible for most of the nationally owned public lands and natural resources. This responsibility entails fostering the wisest use of land and water resources, protecting fish and wildlife, preserving the environmental and cultural values of national parks and historical places, and ensuring the enjoyment of life through outdoor recreation. The Department monitors energy and mineral resources to ensure that their development is in the Nation's best interest. Also, the Department has a major responsibility for residents of American Indian reservations and Island Territories under the administration of the United States.

Frequently, the Department relies on data acquired by satellite and aircraft sensors to inventory and monitor lands under its management, and maintains an active program of research and technique development in remote sensing, digital cartography, and geographic information systems. During 1986, bureaus and agencies of the Department of the Interior participating in remote sensing and digital data applications included the Bureau of Indian Affairs, Bureau of Land Management, Bureau of Mines, Mineral Management Service, National Park Service, U.S. Fish and Wildlife Service, and U.S. Geological Survey.

Remotely Sensed Data Acquisition and Processing

Satellite Data

The Earth Resources Observation Systems (EROS) Data Center of the U.S. Geological Survey (USGS) continued to support the transition of Landsat operations, data marketing, and data sales from the National Oceanic and Atmospheric Administration (NOAA) to the Earth Observation Satellite (EOSAT) Company, the commercial operator of Landsat. The EROS Data Center supported NOAA and EOSAT in archiving, processing, and distributing Landsat data products to users.

During 1986, approximately 40,000 Landsat Thematic Mapper (TM) and Multispectral Scanner (MSS) images were processed and added to the archive, bringing the total U.S. archive to 750,000 images. The EROS Data Center maintains a computer-based catalog and inquiry system for these images and listings of over 800,000 images held by certain foreign Landsat ground receiving stations. During 1986, approximately 26,000 film and digital Landsat products were generated and distributed to users worldwide.

NOAA and the USGS have developed a system at the EROS Data Center to receive and process NOAA's Advanced Very High Resolution Radiometer (AVHRR) data of the conterminous United States. In 1986, design and procurement of the system were completed, and operation is scheduled to begin in 1987. The system will generate selected AVHRR data that are optimized for land science applications consistent with the Department's research and land management responsibilities, and for other Federal research purposes.

Aerial Photographs

In 1986, contracting for the National High Altitude Photography (NHAP) program was completed. The initial phase, NHAP I, was begun in 1980 by participating Federal agencies to acquire simultaneous 1:80,000-scale black-and-white and 1:58,000-scale color-infrared aerial photographs of the conterminous United States during the nongrowing (leaf-off) season. Photographs covering over 2,900,000 square miles, or about 95 percent of the conterminous United States, were acquired under NHAP I and are available to the public from the USGS and the U.S. Department of Agriculture. It is anticipated that all photographic acquisitions for NHAP I will be completed by the end of 1987.

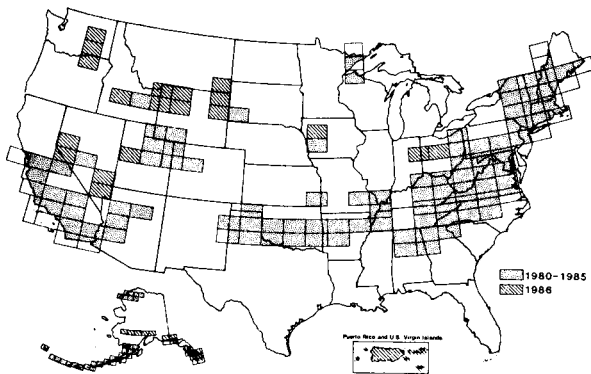
The second major phase, NHAP II, began in 1985 as a 5-year plan to acquire 1:80,000-scale black-and-white and 1:58,000-scale color-infrared aerial photographs of the conterminous United States with two differences from NHAP I: image acquisition is scheduled during the growing (leaf-on) season, and work

is contracted by complete State units rather than by 1° blocks. During 1985 and 1986, 460,192 square miles were contracted; by the end of 1986, 80 percent of the 1985 acquisitions and 57 percent of the 1986 acquisitions were completed, covering a total of 200,800 square miles.

After a reassessment of individual Federal and State agency needs, the NHAP Program was redesigned to meet current requirements for higher resolution aerial photographs. The new program, called the National Aerial Photography Program (NAPP), will provide complete, standardized, and uniform-quality coverage of the 48 conterminous United States. New photographs will be acquired from an altitude of 20,000 feet with a single 6-inch focal length camera exposing color-infrared film at a scale of 1:40,000. The photographs will be centered on quarter sections of standard 7.5-minute quadrangles. NAPP will begin in 1987, and photographs of all or parts of 12 States will be acquired.

Side-Looking Airborne Radar Data

In 1986, the USGS Side-Looking Airborne Radar (SLAR) program continued, and a contract was awarded to acquire data covering approximately 206,000 square miles in the conterminous United States, Alaska, the



Status map showing extent of coverage by the USGS Side-Looking Airborne Radar (SLAR) program.

Commonwealth of Puerto Rico, and the Virgin Islands. From 1980 through 1986, SLAR data were acquired, or contracted for acquisition, for more than 941,000 square miles in the United States. Acquisition areas are selected after a review of areas proposed by State geologists and scientists from private industry and the USGS. Data are available

as image strips, 1° by 2° mosaics, and, for selected areas, as computer-compatible tapes.

Digital Data Processing and Transmission

Software Development and Implementation

In 1986, the cooperative development efforts of the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center and the USGS culminated in the implementation and release of the Land Analysis System (LAS) for general use by several government and academic organizations. LAS is an image processing and geographic information system that provides a broad range of capabilities, including image processing and analysis, tabular data processing and analysis, geographic data capture and manipulation, and geometric registration and image mosaicking. The system is used for enhancing Landsat digital images, producing geometrically registered and mosaicked image maps, integrating raster and vector data sets, and merging different image types, such as Landsat TM and the French Systeme Probatoire d'Observation de la Terre (SPOT). LAS was developed to link several heterogeneous computer systems, using local-area network file transfer over high-speed communication lines, and is used in approximately 20 facilities throughout the United States. NASA and the USGS are working together to enhance system capability and improve system portability.

Use of LAS software in low-cost, workstation-oriented computer systems continues to receive high priority within the USGS, and is expected to result in a wide range of applications far beyond the basic image processing capabilities that were envisioned. The availability of workstation hardware from Digital Equipment Corporation (MicroVAX systems) allowed easy application of most of the LAS. Because the LAS program also supports use of applications modules under the UNIX operating system, it can be installed on a variety of 32-bit, multiprocessing, supermicro-based workstations.

During 1986, the National Park Service (NPS) continued to adapt software to the UNIX operating system, allowing users to run it on very powerful, yet significantly lower-cost, hardware. The NPS cooperated

with NASA's National Space Technology Laboratories to produce an operational UNIX-based version of the Earth Resources Laboratory Applications Software (ELAS). ELAS is used by NPS and other Federal and non-Federal agencies to process and classify multispectral scanner, radar, and other remotely sensed data from satellite and aircraft platforms. Geographical Resources Analysis Support System (GRASS), developed by the U.S. Army Corps of Engineers, is another UNIX-based software system adopted by the NPS. GRASS is user friendly and can process both raster and vector data. Both ELAS and GRASS are being installed on UNIX-based workstations for operational use in national parks and other NPS units.

Polar Satellite Communications

The USGS is participating in a joint project to install and operate the South Pole Satellite Data Link, the first satellite telecommunications link from the South Pole to the United States. Participants include the National Science Foundation, University of Texas Applied Research Laboratories, Bendix Field Engineering Corporation, ITT Antarctic Services, NASA, and NOAA. Installed in 1985, this telecommunications system was the primary means of transmitting USGS scientific data daily from the South Pole during 1986. Further modifications to the system are planned, and it is expected that a broader range of scientific data will be transmitted in the future.

Remote Sensing Applications

Cooperative Federal Land Remote Sensing Research Program

The USGS and NOAA signed an agreement to establish the Cooperative Federal Land Remote Sensing Research program that will be located at the EROS Data Center. The objective of this program is to conduct land remote sensing research, applications development, and user education. The program is expected to promote greater operational and research use of remotely sensed data and related technology within Federal and State governments, academia, and the private sector.

Renewable Resources

A cooperative research project between the NOAA Satellite Research Laboratory and the USGS is underway at the EROS Data Center to evaluate satellite assessment of land surface features and climatic variables. The objective of the study is to determine if relationships can be established between routinely available ground-based data and satellite measurements. Satellite data include daily and weekly composites of AVHRR Global Area Coverage data for the Great Plains region of the United States. Geographic information for the area includes political, topographic, climatic, and land resource data bases that will be used to stratify the satellite and ground-based observations. The satellite and ground-based data sets are expected to contribute to the overall understanding of land surface climatology.

The National Wetlands Inventory Project of the U.S. Fish and Wildlife Service (USFWS) identifies and classifies the Nation's wetland habitats with the use of high-altitude aerial photographs from the NHAP Program. The USFWS works with the Defense Department's Computer-Assisted Photo Interpretation Laboratory, and other groups, to evaluate digital mapping capabilities, such as wetland data digitization, use of computer graphics, and analytical photogrammetry. The USFWS will use these automated methods when it becomes cost-effective to do so.

Since the early days of the Landsat program, the Bureau of Indian Affairs (BIA) has used remotely sensed data from satellites for natural resource applications. Early projects emphasized applications development, while current activities emphasize operational use. In spite of decreasing program budgets and personnel ceilings, BIA has assigned high priority to these activities as a means of achieving natural resource management objectives. BIA plans to conduct operational and experimental projects, using both Landsat and SPOT satellite data, that include both visual interpretation and digital analysis to determine information content. Projects that are already in progress on reservations include: San Carlos Agency, Arizona—a land cover and land use map of the reservation for use in a range survey; Yakima Agency, Washington—evaluation of SPOT and Landsat TM data to improve natural resource interpretation; Hopi Agency, Arizona—incorporation of remotely sensed data

into a geographic information system; and Warm Springs Agency, Oregon—evaluation of SPOT and Landsat TM data to assess forest resources.

The NPS continues to acquire and use Landsat TM data, combined with USGS digital elevation model data, to develop digital data bases for more than 30 million acres of national parks in Alaska. In conjunction with the data base development, the NPS is experimenting with enhancement techniques for Landsat TM data to detect all-terrain vehicle (ATV) trail damage to arctic tundra. Although the width of most ATV trails is less than the satellite sensor resolution, many trails are being detected because they contrast sharply in tone with the naturally vegetated surroundings. As satellites with higher spatial resolution sensors become available, these techniques may serve as an effective way to monitor ATV damage and subsequent vegetation recovery.

Hydrology

The USGS is using remotely sensed data in a variety of water resources investigations, including studies of groundwater, water quality, water use, evapotranspiration, and snow and ice. In most instances, Landsat MSS and TM data are used to map land use/land cover and terrain features as an intermediary step in estimating hydrologic conditions. For example, several studies are concerned with estimating the amount of ground water that is pumped for agricultural irrigation. In such studies, irrigated crop types are determined and their acreage calculated from a digital classification of Landsat data. This information is then integrated with other variables, such as climatic conditions, into a model that calculates the irrigated water demand of specific crops.

The USGS is conducting research on use of ground water on the Columbia Plateau. Landsat MSS data were used to determine acreage of agricultural crops by water-use category; spectral classification of the MSS data was used to identify crop categories; and a geographic information system was used to store, analyze, and display the data. Individual crops were more accurately distinguished using Landsat TM data than Landsat MSS data. Acreage of crops by water-use category was summarized by quarter-township units and incorporated into a water-use model.

As part of NASA's International Satellite Land Surface Climatology program, the USGS is using data collected by Landsat and AVHRR to study the relationship between irrigation development and climatic change in western Nebraska. Data collected during selected years that represent transformations in vegetation greenness and land surface albedo (brightness) will be analyzed and compared to changes in land cover.

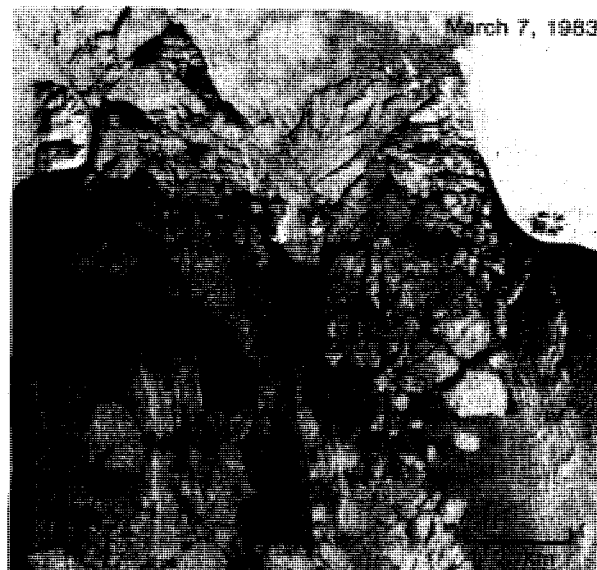
Landsat TM images are being produced by the USGS to support water resource investigations in California and Nevada. The images are used for mapping water-bearing formations and distinguishing vegetation that indicates the presence of ground water. Also, Landsat data are being analyzed to identify and map agricultural crops along the lower Colorado River Valley and to determine the amount of irrigation water that is used by the crops and returned to the atmosphere by evapotranspiration. The information is used to allocate and regulate the use of irrigation water. This work is being performed in conjunction with NASA and the State of Arizona. In addition, Landsat TM images are being used to monitor the extent of growth of hydrilla and other submersed aquatic vegetation in the upper Potomac River estuary near Washington, D.C.

Data from active and passive microwave sensors are being used to develop techniques for characterizing and measuring snow and ice properties. Data from the Nimbus-7 scanning multichannel microwave radiometer are used to measure snow distribution, snow water equivalent, and snowmelt initiation time and progression patterns. These remote sensing measurements are coupled with selected field measurements of the vertical distribution of snow density, snow grain size, temperature, and the presence of crust and ice layers in the snowpack. This approach has demonstrated considerable potential for providing immediate information on snow characteristics to forecast snowmelt runoff in large river basins like the upper Colorado River.

The USGS used image enhancement techniques to reveal detail on Landsat MSS and TM images of Antarctic snow and ice fields. This process allows both the identification of blue ice patches, which commonly contain surface concentrations of well-preserved meteorites, and tracking of specific glacial features, from which accurate glacial flow rates can be determined.



Rapid spring break-out of ice flows into the Bering Sea is shown in these Landsat MSS band 7 images acquired on March 6 and March 7, 1983. Ice moves southward through the Bering Strait from the Chukchi Sea into the northern Bering Sea when winds blow from north to south through the



Strait, and the normally south-to-north oceanic current is reversed by sea-surface tilt induced by atmospheric pressure. Daily ice displacements during this time were generally on the order of 35 km per day but ranged as high as 70 km per day.

Oceanography

Through the Outer Continental Shelf Environmental Assessment program of the Alaska Region Studies Program, the Minerals Management Service funds a remote sensing project that acquires, analyzes, and archives satellite images and other remotely sensed data of the U.S. Arctic region. The archive contains selected high-quality Landsat and AVHRR images that are used to study the forms, seasonal distribution, and movement of sea ice. In 1986, studies continued to correlate ice motion, such as ice-ridge building and formation of polynya (permanent or semipermanent open-water areas within an ice-covered sea), with meteorological conditions. Specific studies were conducted in the Bering Straits—ice-ridge building and ice movement; Yukon Delta—ice movement and distribution; Beaufort Sea—ice distribution and concentration during summer; and Chukchi Sea—ice behavior. Also, satellite data were used to delineate suspended sediment plumes, verify the presence of ocean circulation features, and identify areas of high plant-pigment concentrations in the sea.

Geology

Geologic Mapping and Analysis. Significant advances were made by the USGS in an-

alyzing satellite and airborne visible and near-infrared reflectance measurements for lithologic determinations. Certain hydroxyl-bearing minerals, commonly associated with metal deposits, exhibit diagnostic reflectance characteristics that can be detected in rock and soil. Digital analysis of images recorded in the visible and near-infrared parts of the electromagnetic spectrum allows identification of these minerals and compilation of maps showing their distributions. In highly vegetated terrain, subtle reflectance differences, caused by anomalously high copper content, also were detected using high spectral resolution measurements. These techniques have considerable potential for mineral appraisal studies, especially as advanced imaging systems are placed into orbit.

Mine Development and Safety Monitoring. To improve the ability to predict ground hazards in underground coal mines, the Bureau of Mines continued its research on the application of Landsat MSS data to geologic lineament analysis. In 1986, activities concentrated on ground-data collection to verify correlations between surface lineament features and subsurface ground conditions. Based on the analysis of remotely sensed data, a map of potential mine hazards was developed for an underground coal mine near Orangeville, Utah. Subsequently, the map was compared to roof conditions in the mine

and roof failures experienced in areas of active mining. About 80 percent of the deteriorating and fallen roof areas in the mine, including areas of heavy water inflow, were found within the hazardous zones that were identified by lineament analysis. This result seems to verify the methodology that is being developed by the Bureau for predicting ground hazards in mining by using remote sensing techniques. On the other hand, five lineaments mapped from Landsat data of the coal mining region in southwestern Pennsylvania were compared to subsurface geologic conditions by using geophysical traversing and soil moisture sampling. The results failed to show any significant subsurface geologic disturbances that could be correlated with the lineaments. Thus, accurately predicting subsurface ground hazards, using remotely sensed data in various geographical regions, remains a critical issue for further investigation.

Planetary Studies. In January 1986, the Voyager II spacecraft, launched in September 1977, flew past Uranus and its satellites. Approximately 7,000 images were transmitted to Earth and were used to construct maps and to interpret the geologic history of several



The complex geologic history of Miranda, one of the moons of Uranus, is revealed in this mosaic of images acquired by Voyager 2 on January 24, 1986. At least three terrain types of different age and geologic style are evident: ancient, cratered terrain consisting of rolling subdued hills and degraded craters (right of center); a grooved terrain with linear valleys and ridges (right and left sides); and a complex terrain in which intersecting curvilinear ridges and troughs are abruptly truncated by the linear, grooved terrain (left of center).

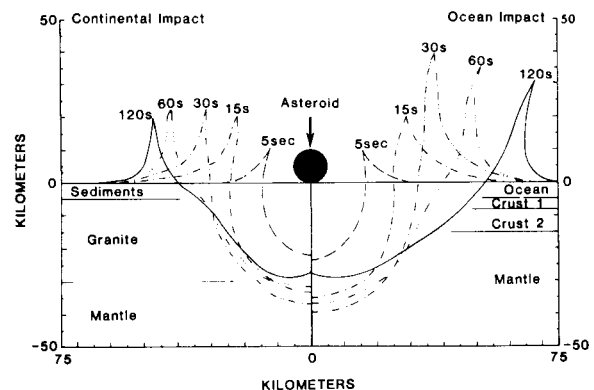
satellites of Uranus. The images show that the satellite Miranda has a very peculiar surface, suggesting that this body may have been completely broken up by large impacts, and that the large fragments remaining were reformed into the mass currently observed.

New digital mapping techniques were developed to construct a digital image model of Mars at 100-meter resolution and a digital terrain model that has 500-meter vertical

resolution. Both models will be used for all feature map compilations of Mars. The digital image model is an image map or mosaic in a sinusoidal equal-area projection. This projection is a convenient configuration for digital storage, and it can be transformed into any standard map projection for map publication. The digital terrain model will be derived from a new photogrammetric model of the planet Mars that has recently been completed. The model involves simultaneous solutions for 1,250 images and 5,000 control points, and it incorporates spacecraft occultation and Earth-based radar data. This redefinition of the shape of Mars' surface is the basis for a new series of topographic maps at 1:2,000,000 scale.

Geologic studies of Mars from image data indicate that ice may be present near much of the Martian surface, and that Mars may contain more water than has been predicted from studies of its atmospheric composition. Other geologic studies of Mars include the identification of potential landing sites for future manned or unmanned missions that might involve returning samples of Martian surface materials to Earth.

Meteorite impact craters on Earth are being studied to improve understanding of the absolute time scale in which cratering occurred. Information gained from these studies can be compared to the surface ages of other planets and satellites. Detailed numerical modeling of a large meteorite impact that may have been responsible for the worldwide extinction of species millions of years



Computer simulation of a 10-km diameter asteroid impacting continental and oceanic environments of the Earth at a speed of 20 km per second. In this simulation, the craters reached maximum depths of nearly 40 km about 30 seconds after impact, and displaced material then rebounded violently upward. In the ocean impact event, the rim crest rose almost 40 km in altitude and rushed outward at speeds of several km per second to cause enormous tsunamis. More than 100,000 km² of rock and ocean were ejected into the atmosphere and over the surrounding area in the two simulations.

ago, such as dinosaurs, is being conducted to determine the nature of the resulting landforms and the amount of meteoric and terrestrial material that was ejected into the atmosphere. This modeling will help to determine the effects of large asteroidal or cometary impacts on past and future life on Earth.

Cartography

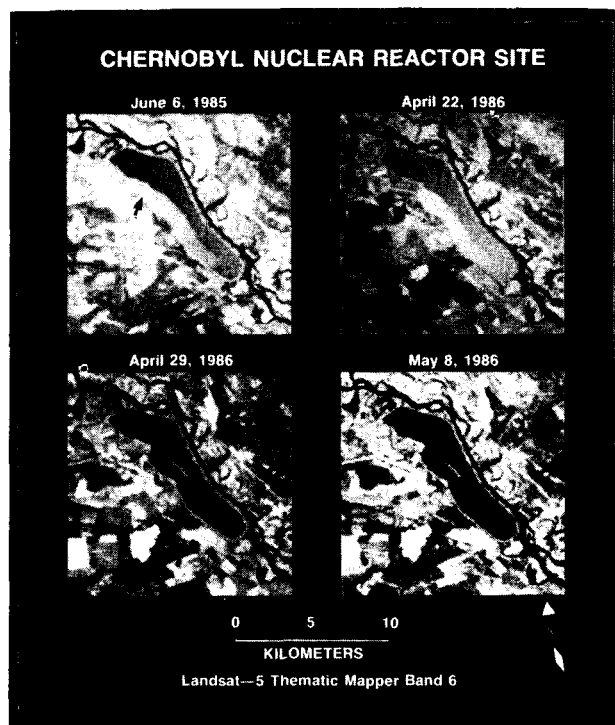
Satellite Data Processing and Image Mapping. In 1986, the USGS continued research investigations to refine procedures for producing satellite image maps. Achievements include incorporating deconvolution (restoration) software into the Landsat MSS and TM data processing system, and modifying software to process AVHRR data. In addition, procedures were improved for converting digital image data to hard-copy color transparency film products that are more suited to processing on a graphic scanner-plotter, which produces the halftone reproducible film required for lithographic printing.

Landsat MSS and TM restoration procedures were developed by the University of Arizona under contract to the USGS. The restoration procedure improves image quality by removing sensor-introduced degradations, such as optical blurring and electronic signal smearing. This procedure is used as one of the steps in digital processing to produce image maps. Restoration is performed during the process of geometric rectification, where data are resampled and registered with other images or to a map base. Images rectified using the restoration procedure are both visibly sharper and of higher radiometric fidelity than those rectified without the procedure. Currently, research is under way at the University of Arizona to develop image restoration for AVHRR data. In addition, the USGS and the University will soon enter into a cooperative agreement to develop this capability for high-resolution images acquired from the SPOT satellite.

The USGS continued its experimental program to produce image maps from Landsat MSS and TM data, incorporating digital processing techniques into their production. In 1986, Landsat MSS image maps (scale 1:250,000) that were printed include Denali National Park and Preserve, Alaska; Richmond, Virginia; and Mariposa, California. To produce a false-color image map of the conterminous United States, at a scale of approxi-

mately 1:4,000,000, AVHRR data were collected for the Eastern United States to merge with data already available for the Western States; and AVHRR data collection was initiated to produce a similar product for the State of Alaska. In addition, research was conducted to determine the largest scale AVHRR image map that can be produced to cover large unmapped areas of the world.

A Landsat MSS image map of the Araxa area, approximately 350 miles northwest of Rio de Janeiro, Brazil, was printed by the USGS for the National Research Council of Brazil. The comparison printing was made at 1:250,000 scale using halftone enlargements from a graphic arts color scanner-plotter and photographic copy camera. The halftone enlargements were made from continuous-tone, silver film-negative separations digitally processed at 1:1,000,000 scale. These test prints will serve as printing guides for a map project proposed by the Fundacao Universitaria Jose Bonifacio and the Federal University of Rio de Janeiro, Brazil. The Council plans to use a series of 1:250,000-scale Landsat MSS or TM image maps to expand the economic



Sequential Landsat thermal infrared (band 6) images of the Soviet nuclear reactor site at Chernobyl. The June 6, 1985 and April 22, 1986 images show the normal tone pattern associated with warm water discharge from the reactor (arrow). Warm water (lighter tones) cools as it circulates counterclockwise in the pond. Water in the pond is uniform in tone on the April 29 and May 8, 1986 images, indicating that the cooling system had been shut down following the April 26 disaster.

development of Brazilian mineral resources. The demonstration printing was completed in time for exhibit at the 1986 Pan American Institute of Geography and History (PAIGH) XV Consultation on Cartography in Rio de Janeiro, Brazil.

Shortly after the April 26, 1986 disaster involving the Soviet nuclear power plant at Chernobyl, the USGS EROS Data Center acquired Landsat TM data and SPOT high-resolution visible (HRV) panchromatic data on the site, and applied digital processing techniques to maximize the interpretability of images. Landsat mid-infrared TM images (bands 5 and 7), acquired on April 29, showed direct evidence of the high-temperature heat source associated with the damaged reactor. These spectral bands may be useful to detect other high-temperature thermal anomalies that might be associated with active lava flows and forest fires. Data in Landsat TM band 6 were used to observe differences in water temperature in the cooling pond adjacent to the power plant before and after the disaster. The 10-meter SPOT panchromatic image revealed significantly greater spatial detail in the vicinity of the reactor site than the Landsat TM data. In addition, TM and SPOT data were combined, using data-merging and color-transformation techniques, to produce a single image that presented much of the multispectral information available only from the Landsat TM data. In the future, these techniques will be used to merge different types of satellite data into single-image maps.

Sonar Image Mapping. In response to the Presidential Proclamation establishing the Exclusive Economic Zone (EEZ) over submerged lands extending 200 nautical miles seaward from the coasts of the United States and certain possessions, the USGS continued to collect and analyze sonar image data. USGS is producing a series of reconnaissance maps of the sea floor of the EEZ area by using data from the GLORIA (Geologic Long-Range Inclined ASDIC) system, designed and developed by the Institute of Oceanographic Sciences, United Kingdom. As presently configured, the GLORIA system operates in water depths from 150 meters to the deepest parts of the ocean.

During 1986, GLORIA data of Pacific Ocean areas off the West Coast of the United States were published in an atlas of thirty-three 2° by 2° map sheets. Also, associated profiles of magnetic and seismic data were

included. In 1986, data of the Gulf of Mexico and offshore areas around Puerto Rico were analyzed, using the USGS-developed Mini Image Processing System. Substantial image processing and mosaicking are required to make GLORIA data useful for interpretation purposes. Processed data continue to reveal new information about the geology of the ocean floor. For example, analysis of data from the Gulf of Mexico revealed topographic features, such as basins and escarpments associated with the flow of salt that was mobilized from the depths by pressure from the weight of overlaid sediments. Other features include massive debris flows and meandering submarine channels over 100 kilometers long through which sediment-laden currents are believed to flow.

Aerial Profiling of Terrain System. The USGS completed an application test program and managed operational projects using the prototype Aerial Profiling of Terrain System (APTS). The system demonstrated the feasibility of using an airborne precision laser profiling and tracking system to collect elevation data. The APTS is composed of a precise inertial navigation system that is used to interpolate aircraft position and orientation between laser tracker updates; a pulsed laser profiler measures the distance from the aircraft to the ground. The prototype system demonstrated that it can measure terrain profiles with horizontal accuracy of 60 centimeters and vertical accuracy of 15 centimeters. Because the prototype APTS has had extensive operational use and many components have become unreliable, the system will be taken out of service in 1987. Work is underway with the Charles Stark Draper Laboratory of Cambridge, Massachusetts to develop the design specifications for a system that will use the satellite-based Global Positioning System and take advantage of other new technology.

Global Positioning System. The Global Positioning System (GPS), a satellite-based navigation system under development by the Department of Defense, has the potential to revolutionize surveying technology. The USGS recognized this potential and helped to support the development of Texas Instruments TI-4100, the first portable GPS receiver system designed for field survey work. In 1986, five of these units were used to develop an operational capability to perform GPS surveys and begin applications testing. The USGS has investigated the use of GPS for crustal motion stud-

ies, and has taken a lead role in the development of more precise satellite ephemerides. A 50-station network was established in the Sacramento Valley to monitor land subsidence; and the USGS and NOAA are using the GPS to determine the elevations of selected points around Phoenix, Arizona so that land subsidence caused by extraction of ground water can be mapped. Future research and development efforts will focus on achieving maximum accuracy using the system for crustal motion studies, and for establishing a dynamic positioning capability.

International Activities

The USGS is working with the National Bureau of Surveying and Mapping (NBSM) of the People's Republic of China under a Protocol for Scientific and Technical Cooperation in Surveying and Mapping Studies Concerning Scientific and Technical Cooperation in the Application of Remote Sensing Information to Cartography. Under this Protocol, four scientists from the NBSM visited the USGS during 1986, including two who spent 12 weeks in the United States studying digital image processing techniques for remotely sensed data; subsequently, two USGS scientists visited China for four weeks to continue the research and training activities. Scientific exchanges under the Protocol are planned for three more years.

In 1986, the USGS conducted a 5-week remote sensing workshop at the EROS Data Center for 10 scientists from 6 countries. The workshop covered applications of Landsat data for geologic, hydrologic, and vegetation analysis.

Department of Agriculture

In 1986, the remote sensing program of the U.S. Department of Agriculture (USDA) emphasized basic applications research and the effective use of data from space-based sensors. Operational activities in agencies of the Department, such as the Soil Conservation Service, were supported by the Remote Sensing Research Laboratory. The Forest Service continued developmental work on Geographic Information Systems, using space-based remotely sensed data as an information source. The National Agricultural Statistics Service, and the Foreign Agricultural Service continued the development and use of space-based remotely sensed data to assess agricultural conditions and to provide more accurate crop statistics.

Remote Sensing Research

The new Remote Sensing Research Laboratory, established as part of the Agricultural Systems Research Institute, Agricultural Research Service (ARS), is a focal point for remote sensing research. Located at the Beltsville Agricultural Research Center in Maryland, the Laboratory's primary mission is to conduct basic and applied remote sensing research that serves agencies of the Department. Currently, the Laboratory provides support to the Soil Conservation Service, for monitoring and inventorying resources, and to the Foreign Agricultural Service, improving that agency's ability to use the environmental satellites of the National Oceanic and Atmospheric Administration (NOAA). Research that will provide long-term benefits to programs involves the calibration of various satellite remote sensing systems. Calibration allows consistent and accurate values to evaluate satellite data.

Working closely with the Remote Sensing Research Laboratory, the Hydrology Laboratory of the ARS participated in the first International Hydrologic Atmospheric Pilot Experiment (HAPEX) conducted in France. The goal of this experiment was to improve climatological understanding. Remotely

sensed data, from aircraft and multiple satellite platforms, were used to extrapolate point measurements of water balance. For example, forecasting the amount of water available for irrigation required timely information on snow cover and the extent of melting. Snow runoff modeling involved mapping snow covered areas and estimating the amount of snow water from data obtained by research satellites. In addition, using data from Landsat's Multispectral Scanner (MSS), the Hydrology Laboratory developed a procedure to estimate amounts of sediment concentration. This research will enhance efforts to monitor the quality of water in lakes, streams, and rivers.

The ARS participated in a cooperative experiment with the U.S. Geological Survey and the University of Arizona's Maricopa Agricultural Center on the use of remotely sensed spectral data for large-scale farm management. Because relationships between spectral data, soil, and crop properties are not sufficiently understood and documented, the use of remotely sensed data for operational farm management decisions has not yet occurred. A detailed examination of what remotely sensed data can provide from observations of soils and crops is a logical first step toward developing a farm-oriented remote sensing system. However, such an examination is complex because it must include remotely sensed data at different spectral and spatial resolutions, and a variety of crops at different growth stages and health conditions.

The objective of the experiment at the Maricopa Agricultural Center was to collect a comprehensive set of remote and ground-based spectral data on agricultural fields. As the experiment evolved, additional research needs were identified, and the number of participants multiplied. The experiment evolved into an intensive endeavor; each day that Landsat-5 passed overhead, weather and equipment permitting, numerous measurements of the atmosphere, soil, and plants were made.

In cooperation with specialists at USDA's Soil Conservation Service, ARS scientists analyzed Landsat images for saline and alkaline soil problems. The images were taken

during the years 1973, 1978, and 1984 in four counties in northwestern Oklahoma. Although specific areas of saline and alkaline problems could not be identified precisely, productive, and consistently used soils could be detected.

Other research focused on relating plant yield characteristics and plant responses to environmental conditions, such as weather, soil, stress, and a variety of field management practices. These relationships allowed a sound basis for estimating the yield of important world market crops. In conjunction with satellite data on crop growth and yield models, a major research effort focused on a model based on infrequent observations made by Landsat's MSS. In an experiment, use of the model improved the average yield estimate of sample grain sorghum fields to within three percentage points of the observed value. Currently, this technique is being tested using observations of sample corn, soybean, and wheat fields in Iowa, Nebraska, and North Dakota.

Traditional data bases and decision processes have been incapable of fully supporting forest fire operations in Okanogan National Forest in eastern Washington. However, new natural resource data bases, using MSS imagery, digital terrain data, and ancillary information, provided a fully integrated, real-time, computerized fire dispatch system. Additional data bases, such as those projecting timber productivity, and land-ownership, were acquired and installed. The value of data bases for other purposes also was recognized in the acquisition process.

Using Landsat data for information, Geographic Information Systems (GIS) were developed for other National Forests. For example, Flathead National Forest in Montana is developing a GIS for forest management. The data base will improve and enhance use of data for forest classification. In turn, the vegetation classification from the project will serve as the vegetative section in the GIS data base.

An unusual application of Landsat data was to map grizzly bear habitats in Lewis and Clark National Forest. This project used three Landsat images of the east side of the Continental Divide in northwestern Montana. The finished project will allow personnel at Lewis and Clark National Forest to manage more effectively those areas with activities ranging from oil and gas exploration to the habits and practices of grizzly bears.

Satellite remote sensing activities in the Forest Service use both MSS and Thematic Mapper (TM) data from Landsat spacecraft. The Forest Service has two operational image processing systems: Region and Forest Pest Management, located in Atlanta, Georgia, and the Okanogan National Forest in the Pacific Northwest Region. Due to the development of Geographic Information Systems (GIS), and a general improvement in computer literacy in the Forest Service, interest in image processing is increasing.

There is a continuing effort in the Pacific Southwest Region of the Forest Service to use Landsat data on vegetation to inventory timber. Initially, MSS data were used; in 1986, TM data were used for the first time. Image data in digital form are analyzed using computers, which facilitate the classification of vegetation and the stratification of commercial timber stands for mapping, area summations, and ground sample selection. To evaluate the results accurately, ground plots were established that represented major vegetation types. On the first National Forest inventoried, the precision of the net timber volume estimate was plus or minus 7 percent of the total volume of 560 million cubic meters.

An evaluation of MSS imagery to classify lodgepole pine mortality, caused by the mountain pine beetle, has been completed. This work began in 1981 by the School of Forest Resources, North Carolina State University, under a cooperative agreement with the Forest Service. Included in the test site were two Ranger districts in the Targhee National Forest, Idaho, an area that experienced onslaughts of mountain pine beetle that were catastrophic. Based on the percentage of potentially marketable volume killed, lodgepole pine stands were classified into three mortality classes. These classes corresponded well with ground conditions; 76 percent of the plots for which ground data were available were classified correctly.

In cooperation with the National Aeronautics and Space Administration, the Southern Forest Experiment Station is finishing a pilot study on the use of TM data to classify forest cover. The study area consists of two adjacent parishes in northern Louisiana.

An evaluation of the utility of TM data for the detection of forest damage was conducted by the National Vegetation Survey, an element of the Terrestrial Effects Task Group of the National Acid Precipitation Assessment Program. Initial research indicates that mea-

surements, based on ratios of TM bands, may be useful to detect and quantify forest damage at sites reported to have received acid precipitation. In 1986, TM data were evaluated on three sites in the eastern United States to determine the level of forest damage. If the analytical procedure proves to be valid, it may become a valuable tool for conducting surveys to detect forest damage.

Remotely sensed data from Landsat and NOAA polar orbiting environmental satellites continued to be good sources of information for assessing domestic and foreign crops by the National Agricultural Statistics Service (NASS), and the Foreign Agricultural Service (FAS), respectively. Applying results of recent research, as well as findings of earlier applications programs, such as AgRIS-TARS (Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing), NASS used remotely sensed data effectively to improve estimates of crop acreage for winter wheat, corn, soybeans, rice, and cotton in the states of Kansas, Oklahoma, Colorado, Missouri, Iowa, Arkansas, Illinois, and Indiana. Benefiting from the installation of new computer systems with increased capability, FAS continued to use data from Landsat and NOAA's polar orbiting environmental satellites to analyze crop conditions in major agricultural regions around the world. In addition, the unique expertise of FAS's remote sensing analysts was used by the U.S. Agency for International Development to improve grain crop estimates in the Sudan, resulting in better planning and logistical support for food production in that country.

Federal Communications Commission

The Federal Communications Commission (FCC) regulates interstate and foreign communications by radio, television, wire, and cable. It is responsible for developing and operating broadcast services, and providing rapid, efficient nationwide and worldwide telephone and telegraph services at reasonable rates. These activities include protecting life and property through radio communications, and using radio and television facilities to strengthen capabilities for national defense.

Communications Satellites

International Commercial Communications Satellites

At the beginning of 1986, the International Telecommunications Satellite Organization (INTELSAT) global communications system consisted of 16 satellites in orbit; 1 INTELSAT IV, 4 INTELSAT IVA's and 11 INTELSAT V's. During 1986, the INTELSAT V (F-14) was lost due to the launch failure of the Ariane-2 launch vehicle. The INTELSAT IVA (F-1) was decommissioned and, in order to provide enhanced Ku-band coverage, decisions were made to modify two INTELSAT V and five INTELSAT VI satellites. At the end of 1986, INTELSAT maintained 15 satellites in orbit: 1 IV, 1 IVA and 6 V's in the Atlantic Ocean Region; 3 V's in the Indian Ocean Region; and 2 IVA's and 2 V's in the Pacific Ocean Region. Three of the IVA satellites have exceeded estimated maneuver life.

In 1986, the Commission approved the construction and operation of 30 new Earth station facilities to access the INTELSAT system in the Atlantic and Pacific Ocean Regions for INTELSAT (digital) business, and television transmission and reception service.

In 1985, the Commission released its policy statement in CC Docket No. 84-1299 establishing the regulatory policies that will be used to consider applications for satellite systems providing international communication services independent of INTELSAT. The Commission found that separate international systems proposed by the Administra-

tion will provide substantial benefits to international telecommunications users without causing significant economic harm to INTELSAT. Finding that their application met its legal, technical, and initial financial qualifications and public interest considerations, the Commission granted conditional authority to establish separate satellite systems to Orion Satellite Corporation, International Satellite, Inc., RCA American Communications, Inc., Pan American Satellite Corporation, and Cygnus Satellite Corporation. In 1986, the Commission granted conditional authorization to two additional applicants, McCaw Space Technologies, Inc., and Columbia Communications Corporation, to establish separate international satellite systems. Of these applicants, only PanAmSat has reached agreement with a foreign correspondent and initiated the INTELSAT consultation process. Final action by INTELSAT on the PanAmSat proposal is expected in April 1987.

Domestic Commercial Communications Satellites

In 1986, no new domestic commercial communications satellites were authorized for construction and launch. At the end of 1986, 27 domestic satellites were located between 69° and 143° west longitude on the orbital arc; 16 operate in the 6/4-GHz band, 8 operated in the 14/12-GHz band, and 3 operated in both bands.

In 1985, the Commission authorized the construction and launch of 20 additional domestic fixed satellites to provide communication services through the end of the century. Some of these satellites were scheduled for launch in 1986.

The Commission's Advisory Committee on 2° Spacing was established in 1985 to elicit suggestions by industry representatives on the most efficient and economical methods to accommodate satellite operations under reduced spacing conditions. The Committee is divided into working groups to consider issues relating to Earth stations, space stations, and coordination. In June 1986, the Committee issued recommendations on these areas. With respect to

Earth stations, the Committee recommended mandatory manufacturer product qualification tests, and on-site verification tests by operators of all Earth station systems, including transportables. The Committee also recommended that the Commission revise Section 25.209 of the Rules and Regulations on antenna performance standards so that they are more definitive with respect to side-lobe requirements.

On the subject of space stations, the Committee recommended the adoption of certain technical parameters for C and Ku-band satellites, including opposite polarization for adjacent satellites and ground control of polarization switches. To aid in the implementation of 2° spacing, it also proposed the creation of a satellite spacing coordination data book for use by the Commission, and satellite users and operators. The data book would contain data on interference, satellite characteristics, key transmission parameters, and satellite system operation and coordination procedures.

In the area of coordination, the Committee recommended the use of standard video masks for computation of video interference between adjacent satellites; mandatory up-link identification signals for all video transmissions; and adoption of power flux density limits for C-band Earth stations and antennas less than 9 meters in diameter.

The Committee concluded that it should not make a determination at this time on criteria for transponder fill, satellite replacement, and new entries.

Maritime Satellite Service

National and international efforts to establish a future global maritime distress and safety system are continuing. The International Maritime Organization (IMO) is developing the system that will use Standard A and Standard C ship Earth stations through INMARSAT as well as satellite emergency position-indicating radio beacons (EPIRB's) to provide initial distress alerting information from ships to rescue coordination centers. While present plans include satellite EPIRB's operating through COSPAS/SARSAT (polar orbit) satellites, the IMO Maritime Safety Committee is also considering use of L-band EPIRB's through INMARSAT (geostationary orbit). In addition, trials of distress and safety services will be conducted on GOES satellites

in 1987. The global maritime and safety systems are expected to be phased in between 1991 and 1997.

Currently, INMARSAT is leasing three operational and three in-orbit satellites to serve the Atlantic, Pacific, and Indian Ocean Regions. Second-generation satellites, the first of which is expected to become operational in 1989, are being built under INMARSAT specifications, and will have a capacity about triple that of the current leased satellites. INMARSAT currently serves over 5,000 vessels through its 48-member country organization. Seventeen coast stations in 12 countries are in operation with five more expected in 1987.

In 1986, the Commission issued three decisions bearing on the INMARSAT's second-generation satellites. First, the Commission authorized the Communications Satellite Corporation (COMSAT) to participate in INMARSAT's program to procure three second-generation satellites to serve the Atlantic Ocean Region beginning in 1988. Second, COMSAT was authorized to participate in an INMARSAT contract with Arianespace for an additional launch of its second-generation maritime satellite communications system. COMSAT's request for an additional launch was based on uncertainty as to whether the planned July 1988 Shuttle launch would occur. Third, to provide additional backup facilities and to provide currently authorized INMARSAT services via INMARSAT satellites, COMSAT was authorized to lease capacity on the MARISAT system. Due to the serious deficiency in performance of two of INMARSAT's first-generation satellites, and because other satellites were experiencing service irregularities, this authority was deemed necessary. The prospect of a launch delay of second-generation satellites places a greater burden on first-generation spacecraft.

Aeronautical Satellite Service

In October 1985, the Assembly of Parties of the International Maritime Satellite Organization (INMARSAT) adopted amendments to the INMARSAT convention and operating agreement that will allow it to offer aeronautical services. The amendments will take effect 120 days after two-thirds of member countries, representing two-thirds of the total INMARSAT investment shares, have filed no-

tices of acceptance. INMARSAT's first three second-generation spacecraft are being constructed with three megahertz of bidirectional bandwidth in the aeronautical mobile satellite (R) band. Through its subcommittee on Future Air Navigation Systems, the International Civil Aviation Organization has been considering the application of standards for aeronautical satellites in civil aviation. Through the Airlines Electronic Engineering Committee, the aviation community is actively developing an aeronautical satellite system that will provide voice and data services. Aeronautical Radio, Inc., plans to create an international system by interconnecting its terrestrial VHF network with satellite facilities for oceanic coverage. In addition, land mobile satellite applicants are proposing aeronautical services on their systems.

Direct Broadcast Satellite Service (DBS)

Of the eight "first-round" DBS companies previously granted permits to construct Direct Broadcast Satellites, three are actively progressing in the construction of their authorized satellites. These three permittees will use 200 to 230-watt traveling wave tube amplifiers (TWTA) in conjunction with various half-CONUS or full-CONUS beam configurations to provide service across the continental United States. Modifications granted in September 1985 will allow two of these companies to increase transponder capacity from six channels to eight channels per satellite. Projected completion of satellite construction varies for each company from mid-1987 through 1988. These permittees are required to have their satellite systems in operation by the last quarter of 1988.

Additionally, of the six "second-round" applications granted conditional permits in late 1984 and early 1985, one has demonstrated "due diligence" in construction of its satellite system and has been awarded channels, orbital position, and launch authorization. In contrast to the three "first-round" companies, this system will use two 16-channel satellites equipped with 100 watt TWTA's to provide DBS service. Advances in antenna and receiver technology were cited in support of midpower transponder selection. Commencement of DBS operations for this company is scheduled for mid-1989.

Of the conditional construction permits for new satellite systems granted in September

1985, none was able to demonstrate "due diligence" in satellite construction within the time allowed. Accordingly, these permits were cancelled.

In September 1986, three companies were awarded conditional construction permits for new satellite systems. Of these permittees, one has demonstrated "due diligence" and has requested channel and orbital position assignments. This system will use two 16-channel satellites equipped with 125-watt TWTA's to provide DBS service. The system is expected to begin operation in 1991. Three DBS system applications were filed in December 1986 and are currently pending.

On November 25, 1986, the Commission issued a ruling which modified its earlier statements regarding the acceptable uses of the DBS allocation. Provided that certain restrictions are met, nonconforming uses of DBS transponders which do not detract from the goal of introducing DBS service, and which may help advance it, will be permitted.

New Satellite Services

New technology is developing to provide additional uses for satellite-delivered communications. Increased capacity in the 14/12-GHz band allows the development of services using much smaller antennas than feasible in the 6/4-GHz band. This has prompted several applications for large private networks of small Earth stations to provide communication services between various business locations. These applications request streamlined licensing procedures that will enable such networks to be constructed more expeditiously and economically. In April 1986, the Commission issued a declaratory ruling that streamlined processing procedures for pending and future applications.

In addition, on July 12, 1984, in response to a petition from Geostar Corporation, the Commission issued a Notice of Proposed Rulemaking in General Docket No. 85-689, proposing to implement a radio determination satellite system domestically that would allow subscribers to determine latitude, longitude, and altitude, and to exchange brief coded messages using inexpensive hand-held transceivers. In July 1985, the Commission allocated frequencies in the 1610 to 1626.5-MHz, 2483.5 to 2500-MHz and 5117 to 5183-MHz bands for radio determination satellite

service. In August 1986, the Commission granted the application of Geostar Corporation to construct, launch, and operate three geostationary satellites, and one in-orbit spare, to provide radio determination satellite service and ancillary message services.

On January 28, 1985, in response to a petition from NASA, the Commission issued a Notice of Proposed Rulemaking in General Docket No. 84-1234, that proposed to allocate spectrum for a mobile satellite service, to establish technical and regulatory guidelines for the service, and to authorize a licensee. The service envisioned by NASA would provide mobile telephone service in rural areas, long-range vehicle dispatch functions, data transmission and data collection, vehicle position determination, message distribution (paging), and emergency communications. The Commission received voluminous comments concerning the issues raised in the rulemaking. The Commission also received a dozen applications from entities proposing to establish mobile satellite systems. In July 1986, the Commission allocated 27 MHz of spectrum for the provision of this service. In December 1986, the Commission issued a Report and Order that established general policies concerning the licensing of the entity charged with the initial implementation of mobile satellite service. The Commission concluded that joint ownership of a mobile satellite system would be the best way to provide a variety of mobile satellite services to the public. The Commission directed qualified applicants to negotiate a joint venture contract and propose a mobile satellite system to operate in the assigned frequencies.

International Conference Activities

During 1986, the Commission was involved in several activities in preparation for the second session of the Space World Administrative Radio Conference (Space WARC) scheduled for 1988. The objective of the Conference is to guarantee to all countries equitable access to the geostationary satellite orbit and to the frequency bands allocated to space services. The Commission's Advisory Committee, representing industry, continued to make recommendations for the second session's agenda that include allotment planning; a multilateral planning process; simplified procedures for access to the orbit;

and issues involving broadcasting satellites. Also, in May 1986, the Commission's staff attended an International Frequency Registration Board information meeting; and, in June, participated in the Interim Working Party 4/1 that examined technical aspects of conference preparation. In addition, the Commission's staff worked with NASA and other Government agencies to define priorities and positions for the second session and, in particular, to develop appropriate computer capabilities to aid in the allotment planning effort.

Department of Transportation

The Federal Aviation Administration (FAA), a component of the U.S. Department of Transportation, is responsible for regulating air safety, ensuring the safe and efficient utilization of the national airspace system, and fostering the development of civil aviation. To support these responsibilities, the FAA engages in a wide range of research and development activities that enhance safety and increase the efficiency of air navigation and air traffic control.

Aviation Safety

During 1986, developing new standards for civil aircraft seats and restraint systems was one of the most important research projects of the FAA's crash dynamics engineering and development program. The goal of the program was to demonstrate the ability of new systems to minimize hazards to occupants during aircraft crashes. This research effort was the culmination of a long series of cooperative steps between the Federal Aviation Administration, the Department of Defense, the National Aeronautics and Space Administration, and segments of the civil aviation community.

In recent years, developments in both the private and public sectors demonstrated that passenger survivability in accidents could be improved when the forces of impact were within the limits of human tolerance, and that improvements could be adopted without imposing either a heavy engineering or economic burden on the aviation community. Hence, in the early 1980's, the FAA and NASA's Langley Research Center contracted with transport airplane manufacturers to review and evaluate accident data, and define areas where possible improvement in passenger safety could be achieved. In March 1983, the FAA's Civil Aeromedical Institute and the FAA's Technical Center published a joint study on passenger seat and restraint system performance in accidents. The study found a correlation between passenger injuries or fatalities and floor or cabin deformation that caused seat failure; and a correlation between passenger injuries and restraint sys-

tem performance. Crash tests continued at FAA and NASA research facilities.

Although the research and testing program was multifaceted, a key effort was the evaluation of a simple laboratory dynamic test procedure that simulated an aircraft's crash environment. Anthropomorphic dummies were used as surrogates for human occupants; the dummies, seats, and restraining systems were subjected to forces up to 16g; measurements made during the tests were used to evaluate the level of protection offered to the occupants. This technique is superior to the static test procedure used to evaluate aircraft seat performance currently required by the Federal Aviation Regulations, because the static procedure provides only an indication of the structural strength of the seat.

Simulated crash tests were supplemented by a joint FAA/NASA Controlled Impact Demonstration using a full-scale remotely controlled and fully instrumented transport category airplane. In combination with prior work, these tests generated sufficient data to permit the FAA to define the level of occupant protection provided by contemporary transport airplanes. It was determined that incidents of undesirable seat performance were usually related to the displacement of the cabin floor and to excessive lateral inertial loads. By early 1986, the agency determined that seat deficiencies could be eliminated by establishing dynamic test standards that provided the same level of impact injury protection and structure performance as that provided by the airplane structure itself. Consequently, in July 1986, the FAA issued a notice of proposed rulemaking that modified standards for occupant seat protection in transport category aircraft by revising the test criteria for passenger restraints and impact injury. The proposed criteria abandoned static tests in favor of a combined vertical and longitudinal test that simulates an aircraft hitting the ground after a high-rate vertical descent; and a test that simulates a horizontal impact with a ground-level obstruction. With the first test, manufacturers can evaluate the means provided to protect passengers from spinal injury; with

the second, they can assess the effectiveness of the restraining system and the structural performance of the seat. The proposed rule applies only to newly certificated air transport category aircraft.

Concurrent with this effort, the FAA tested the performance of general aviation seats and restraint systems, activity that resulted from deliberations of the General Aviation Safety Panel which was established in 1982 to recommend safety improvements in small airplanes. A special working group of the Panel made recommendations for improved seats and restraint systems for small airplanes that were based largely on experimental and test data generated by the Civil Aeromedical Institute. The Panel recommended that dynamic tests be conducted at up to 26g in order to demonstrate the performance of the seat and restraint system; that the testing program include techniques for demonstrating system performance, even in the case of seriously deformed airframes; and that criteria be incorporated to ensure that the occupants will be protected from irreversible injury in a crash that seriously deforms an airframe. Manufacturers had already developed systems that met the criteria established by the Panel's recommendations and presented their systems to the Institute for evaluation. The Panel's recommendations were presented at the Small Airplane Airworthiness Review Program and received the support of the General Aviation Manufacturers Association. At the end of 1986, the FAA was considering a notice of proposed rulemaking to implement these recommendations.

Aviation Weather

Wind Shear. Adverse weather has always been a challenge to aviation. One of aviation's most serious weather concerns today is wind shear, a sudden change in wind speed and direction. A number of meteorological events can cause wind shear. Large thunderstorms produce strong outflows and downdrafts; gust fronts, found at the leading edges of outflows, can extend several miles away from the rain area and last for periods of an hour or more; and small storms or relatively innocuous looking clouds also are capable of producing intense downdrafts that can be just as hazardous to aircraft as their larger cousins. Wind shear, produced by a smaller

storm known as a microburst, is a violent column of cold or dense air that descends rapidly to meet the ground and expands in all directions, much like water from a garden hose. A microburst is often no more than a mile or two in diameter and lasts for as little as 5 minutes. An airplane flying into this column of air during a takeoff or landing first encounters a head wind, which increases lift, and then a tail wind, which produces a sharp loss in lift. In extreme cases, the tail wind can be violent enough to cause the airplane to crash. Over the past 10 years, encounters with wind shear may have contributed to as many as 25 aircraft accidents worldwide resulting in over 500 fatalities.

Because wind shear is not visible to the pilot's eye, the main protection against this powerful phenomenon is timely warning and avoidance. To make this possible, the FAA and other Federal agencies are pursuing a variety of detection programs. During 1986, the FAA installed an experimental weather radar system at Huntsville, Alabama, to study microbursts and other hazardous weather conditions. The testing was conducted for the FAA by the Lincoln Laboratory of the Massachusetts Institute of Technology. The testing system had previously been located near Memphis International Airport; Huntsville was selected as the new experimental site because its environment is typical of much of the Southeast, where storm-related wind shear and microbursts frequently occur. Lincoln Laboratory had at its disposal two Doppler weather radars, a system of 30 automatic weather stations, and an instrumented aircraft for airborne data collection. Doppler radar has the ability to "see" inside storms and measure both rainfall intensity and the speed of winds moving toward or away from the antenna site. By combining wind information from the two radars, technicians can obtain three-dimensional information on the wind field within a storm. Data collected from these tests will be used to refine computer software that will enable a Doppler radar system to detect wind shear conditions automatically and present this information to pilots and air traffic controllers in a readily usable form. The FAA plans to install Doppler weather radar at major airports beginning in 1989.

In another development, the FAA and the National Aeronautics and Space Administration entered into a Memorandum of Agreement to develop system requirements for

“forward looking” wind shear sensors for aircraft, such as Doppler radar and Doppler lidar. These airborne sensors will “look” ahead of the aircraft and sense hazardous wind shear before the aircraft enters the area. Manufacturers have performed relatively little work in the area of developing forward-looking airborne sensors; rather, they focused their attention on reactive wind shear sensors. Instead of looking ahead, these systems react when an aircraft enters a shear and compare the inertial data of aircraft with air mass data. When a shear is encountered, the airborne equipment sounds an alert and the flight crew is provided with information on how to exit the shear. The FAA and NASA are working closely with the manufacturers of these reactive devices to ensure that forward-looking sensors will function in harmony with the reactive devices.

The FAA also continued to work on the ground-based wind shear detection system currently in operational use, the six-sensor Low Level Wind Shear Alert System (LLWAS). LLWAS employs computer processing algorithms that compare wind speed and direction from sensors on the airport periphery with centerfield wind data. The system alerts air traffic controllers to the presence of wind shear, and the controllers, in turn, issue wind shear advisories to departing and arriving aircraft. During 1986, the LLWAS's at Denver's Stapleton International and New Orleans's Moisant International experienced a high level of false alarms. Since the problem was caused by the sensor's location, the FAA formed a team to assess the siting of all LLWAS sensors at 110 airports in the United States. At the same time, wind experts from Colorado State University and the National Center for Atmospheric Research developed new and more comprehensive siting criteria. Information collected by the team was also used to identify nuisance alarms caused by short-lived, very localized, and meteorologically insignificant events. By the end of 1986, new algorithms were developed to reduce the effect of false alarms. The algorithms will be incorporated into the system as the LLWAS sensors are resited during 1987 and 1988.

In 1986, new algorithms also were devised for the new eleven-sensors LLWAS. The algorithms give the new system an enhanced capability to detect hazardous microbursts, and allow results to be reported in terms of runway coordinates, a form more useful to the user. In 1987, the FAA plans to evaluate

the new algorithms and a new tower cab display at an operational airport.

In addition, a program that began in 1985 to develop a standardized wind shear training program for pilots neared completion. It will provide airlines with tools to train pilots in wind-shear avoidance and techniques to escape from inadvertent wind-shear encounters. The Boeing Commercial Airplane Company, which is developing the program with Douglas, Lockheed, United Air Lines, and Aviation Weather Associates, is expected to deliver the finished product to the FAA in February 1987.

Atmospheric Electrical Hazards. Lightning, static discharge, and other sources that produce electromagnetic transients can pose a serious threat to aircraft in flight. They couple to the aircraft's internal wiring and adversely affect electronic flight controls and avionics. During 1986, the FAA continued its cooperative effects with the Department of Defense, NASA, and the aviation industry to characterize hazards and define their threat to modern technology aircraft. To this end, the FAA produced both advisory circulars and user's manuals to assist officials with problems of electrical hazards in aviation.

Icing. It has long been recognized that flight through supercooled clouds will result in the formation of ice on an aircraft's airframe and engines. The aerodynamic penalties of this ice formation include increased drag, loss of lift, and even loss of control. Ice shed can lead to structural and engine damage. Ice protection systems technology has advanced along with advances in aircraft and engine designs. Proper certification of aircraft for flight into known icing conditions using new or modified ice protection designs depends heavily on understanding equipment limitations under various operating conditions. During 1986, the FAA reported on areas of concern in the application of two concepts: the exuding of an antifreeze solution from porous surfaces on the leading edges of wings; and the de-icing of wing leading edges by electromagnetic impulse shock.

Aircraft Cabin Flammability Standards

On August 20, 1986, a new Federal Aviation Regulation went into effect prescribing tougher flammability standards for materials used in cabins of existing and future airliners with 20 seats or more. The new

standards require manufacturers to use more fire resistant and slower burning materials than those currently allowed for cabin sidewalls, ceilings, partitions, storage bins, galleys, and other interior structures. The use of materials that release lesser amounts of heat during a cabin fire will delay the onset of "flashover," or rapid and uncontrolled cabin fire growth, thereby increasing the time for passenger evacuation. Manufacturers must subject specified cabin materials to a radiant heat test that measures the amount of heat produced by a material when it burns; materials that produce more heat or burn faster than the prescribed standards are banned. The rule goes into effect in two stages, stretching over a 4-year period.

Earlier, on June 16, 1986, the FAA adopted more stringent fire safety standards for air transport cargo and baggage compartments. The new standards apply only to airplanes certificated after the rule's effective date and require manufacturers to use more fire resistant materials for ceiling and sidewall liners in Class C and Class D cargo compartments, which are located below the main cabin. The FAA's fire tests of typical materials currently used in cargo holds demonstrated that only fiberglass meets the new criteria. Also, in order to limit the supply of oxygen available to feed a fire, the new rule restricts the size of the Class D cargo compartment to 1,000 cubic feet.

In a related development, a new FAA rule requiring smoke detectors in the lavatories of all large airliners went into effect on October 29, 1986. Because lavatories are closed from view most of the time, the smoke detectors will warn cockpit crews or flight attendants of a fire that might not otherwise be detected.

Aviation Security

During 1986, the FAA made progress on many fronts in the area of explosives detection. The agency approved several competitive designs for thermal neutron activation (TNA) systems, which will be used to screen checked bagged and air cargo. At year's end, the fabrication on TNA prototypes was well underway, and the initial airport test of a prototype was scheduled for May 1987. In addition, the FAA successfully demonstrated a breadboard chemiluminescent vapor detector. This project has now progressed to the phase of integrating the first vapor detector

into a portal for screening passengers. The first airport test of a prototype chemiluminescent detection portal is scheduled for March 1988. Also, the agency initiated a feasibility study of a chemiluminescent system for screening carry-on baggage and began evaluating a mobile chemiluminescent system for use in aircraft cabins.

Several studies involving detection technologies and concepts were initiated that had their genesis in an FAA request for proposals for new approaches to explosive detection. Out of the 22 responses to this request, 4 were considered sufficiently promising to merit the award of contracts for feasibility studies. In addition, research continued on dual sensor and fast neutron scattering approaches that had been initiated earlier, and both proved feasible. The dual sensor approach, which combines X-rays and thermal neutron activation sensors, offers considerable promise of surpassing the performance of a simple thermal neutron activation system.

In order to strengthen airport concourse security, the possibility of improving discrimination capabilities of current generation metal detectors was investigated. Also, studies were initiated on new infrared and acoustic techniques for detecting both metallic and nonmetallic weapons on passengers. The possibility of enhancing concourse X-ray systems for automated detection of explosives and weapons in carry-on and checked baggage also was explored.

Human Performance Research

Aeronautical Decision-Making. In 1986, six pilot-judgment training manuals, and corresponding audio-visual materials, were revised. The materials addressed the issue of aeronautical decision-making for private, commercial, and rotorcraft instrument-rated pilots, and instructors and multicrew operations. The type of training prescribed in the manuals augments but does not replace traditional pilot training, which stresses knowledge, skills, and experience. However, traditional training methods do not teach judgment; pilots acquire judgment through experience that is directly related to accumulated flight time; and it was surmised that pilots with good experience-based judgment shared airspace with pilots that possessed lesser decision-making skills. Used as part of a standard curriculum, the manuals are intended to teach aeronautical decision-mak-

ing to each segment of civil aviation.

Flight Crew Workload Measurement. In July 1981, the President's Task Force on Aircraft Crew Complement recommended that the generally accepted method of evaluating cockpit work load during aircraft type certification—task/time-line analysis—be augmented by improved subjective evaluation methods. A team of representatives from the FAA, the Air Force, NASA, and manufacturers of air transports was formed to carry out this recommendation. In 1986, two workshops were planned as forums to choose the most appropriate measurement techniques available. An initial part-task and a subsequent full-mission simulation experiment at NASA's Ames Manned Vehicle Systems Research Facility will be used to validate these techniques.

Airport Pavement Research

Through an interagency agreement with the Army Corps of Engineers, the FAA completed the development of a Pavement Maintenance Management System. By using new software called microPAVER, airport owners and operators will be able to allocate resources effectively and establish priorities to maintain and rehabilitate pavements based on conditions, funds available, and expected rates of deterioration. Through another interagency agreement, the Corps of Engineers developed criteria to prevent heaving of airport pavement in cold weather and weakening of subgrades during thaw. At the end of 1986, the criteria were being evaluated at representative airports located in the frost belt.

The FAA also investigated ways to minimize runway and taxiway repair time and improve substitutes for currently used pavement materials, which are expensive to transport. During 1986, contractors completed the development of standards for the effective use of geotextiles. Also, research was conducted on lime, cement, and fly ash combinations for bases, rubber, and polymer additives.

In order to ensure that airport pavements are constructed, rehabilitated, and maintained to FAA standards, in 1986 the agency was in the process of developing acceptance criteria and quality control techniques for airport pavement construction and material. Once developed, the criteria will provide payment of adjustment factors that will be applied to contractors' fees based on how well the pavement meets FAA standards.

Other Safety Developments

General Aviation Propulsion Research. The FAA accelerated its study of alternate fuels for use of piston-engine general aviation aircraft. In recent years, the availability of 80 octane aviation gasoline has diminished while the price differential between automobile gasoline (autogas) and other grades of aviation gasoline has grown. This resulted in pressure on the agency applied by the general aviation community to substitute autogas for aviation gasoline. In examining autogas for aviation use, it was determined that its use can produce fuel system vapor lock, severe detonation in high performance engines, and a significant loss of fuel due to evaporation and venting. The FAA plans to continue testing autogas and alternate general aviation fuels, including gasahols.

Aircraft Turbine Engine Bird Hazard Research. The collision of birds with aircraft, including the ingestion of birds by engines, is both a serious safety hazard and a major cause of property damage. Actions taken to reduce the bird hazard include evaluating the adequacy of bird ingestion engine certification requirements against service experience, and increasing the emphasis on airport bird threat control. In order to determine the adequacy of current bird ingestion certification standards, the FAA gathered data and analyzed engine bird ingestion incidents and accidents. The agency completed a 26-month study and published a report on bird ingestion incidents and accidents involving aircraft powered by large inlet area, high bypass turbofan engines. Also, it initiated a similar study of the Boeing 737, equipped with both JT8D and CFM56 engines, that will provide a comparison of new generation high bypass engines (CFM56's) with older low bypass engines (JT8D's) subjected to the same aircraft bird ingestion exposure. Additional studies are scheduled that will concentrate on business, executive, and commuter aircraft powered by small inlet turbofan and turboprop engines.

Rotorcraft Turbine Engine Rotor Failure Protection. Since 1979, the fleet size, total operating hours, operating hours per craft, and total number of engine failures of civil turbine-powered rotocraft in the free world have increased significantly. In many cases, engine failure generates high-energy fragments that penetrate and escape the engine casing. This results in loss of engine power and can damage critical structures, systems, controls, and other

engines. Such damage has led to fires, loss of aircraft control, hull loss, and occupant injury and death. Consequently, the FAA issued several advisory directives to correct type design deficiencies that were identified as the primary causes of failure on certain engine models. Because type design improvement is not feasible in all cases, an advisory directive was issued that required the use of an internal turbine case containment ring. With a turboshaft engine rotor failure history established during the early 1980's and the feasibility of rotor fragment containment technology for this class of engines demonstrated, the FAA initiated a study to develop a new certification standard for commercial rotorcraft. The study will attempt to provide operational data on rotorcraft turbine failure and the technology for hazard protection.

Anti-Misting Fuel. The FAA completed its test program on the effectiveness of an experimental anti-misting agent that was added to kerosene jet fuels to prevent or reduce the dangers of post-crash fires. The program demonstrated that jet fuel can be modified to provide a significant degree of protection against post-crash fires in impact-survivable accidents. At the end of 1986, the agency was formulating a new program to provide even better means of inhibiting post-crash fires. To prevent combustibles spilled during a crash from igniting, the program will explore the possibility of combining fuel additives with aircraft system modifications.

Airport Rescue and Firefighting. In an effort to minimize rescue and firefighting requirements of U.S. airports, without reducing fire protection for passengers and property, the effectiveness of current and advanced firefighting agents were evaluated. In a series of small-scale laboratory tests, a number of foams were studied and approximately 40 percent were found to conform to firefighting specifications. These promising foams will be evaluated further in a series of large-scale tests.

Helicopter Wake Vortex Study. In 1986, the FAA and the Transportation Systems Center of the Department of Transportation participated in a joint full-scale helicopter flight test program to investigate the wake vortex characteristics of S-76 and CH-53E helicopters. The flight tests measured the trailing vortex intensity, persistence, movement, and decay of the helicopter wake as a function of time. A Laser Doppler Velocimeter was used to acquire vortex intensity data, and an airplane probed the vortex to determine the potential hazard to an

aircraft encountering the wake. Since the trailing vortex of a helicopter is invisible, the helicopters used in the experiments were equipped with smoke generators for the wake flow visualization system. The data collected in this program will be used to explore the feasibility of establishing reduced air traffic control separation standards for mixed terminal area operations.

Air Navigation and Air Traffic Control

National Airspace Systems Plan

Host Computer System. On January 28, 1981, the FAA unveiled the National Airspace Systems (NAS) Plan, a technological blueprint for modernizing and increasing the capacity of the Nation's common civil-military system of air navigation and air traffic control. On November 22, 1986, the implementation of the NAS Plan reached a major milestone with the delivery of the first of a new generation of air traffic control computer systems to the air route traffic control center in Seattle, Washington.

The new host system represents the latest off-the-shelf technology. The "host" designation reflects the fact that the new equipment will use the same basic instruction package as the IBM 9020 computers currently operating at the 20 air route traffic control centers in the contiguous 48 states. The key element is the IBM 3083-BX1 computer. Each installation has two computers, one serving as the primary unit, the other providing support and backup. The new mainframe is ten times faster and has four times the capacity of the older 9020 computer. Tests conducted by IBM demonstrated that the host can handle the air traffic workload projected for 1995 using only 33 percent of its capacity. During fiscal year 1985, the FAA's air route traffic control centers handled 33 million aircraft operations under instrument flight rules; in fiscal 1995, they are expected to handle almost 44 million. This allows for unforeseen traffic growth and also permits the FAA to incorporate new automation functions and upgrade existing functions such as conflict alert and en route traffic metering.

The Seattle host is expected to begin operating during the summer of 1987. Completion of deliveries of host computers to the

remaining 19 air route traffic control centers is expected by the end of 1987. The next phase of the NAS Plan scheduled for completion is the Advanced Automation System, which includes new controller sector suites, computer software, and processors.

Automated Flight Service Stations. The Flight Service Station (FSS) modernization program will consolidate 300 manually operated FSS's into a network of 61 automated hub facilities. In March 1986, the FSS's commissioned the first three automated flight service stations, located at airports in Bridgeport, Connecticut, and Cleveland and Dayton, Ohio. An additional 21 stations were commissioned during the course of the year, and 13 more sites accepted delivery of the automated equipment.

Flight service stations provide pilots with preflight and inflight briefings. They also accept and file flight plans, serve as a communications link for pilots with air traffic control facilities, collect and disseminate aeronautical and weather data, and provide emergency services to pilots in distress. The automated stations are linked by dedicated communications lines to a central Flight Service Data Processing System (FSDPS) located at an air route traffic control center. Weather data, flight plans, and other information are continually fed into the FSDPS. Using computer terminals at the automated facilities, flight service specialists receive quick access to this information, which can be called up on display screens and printed out for future reference. General aviation pilots are the primary users of these services since most airlines have their own flight dispatch facilities.

Voice Switching and Control System. In October 1986, the FAA awarded contracts to AT&T Technologies and the Harris Corporation to develop competing prototypes of a computer-based switching system to control voice communication for en route air traffic control. The contracts represent the first phase of a two-step procurement that will culminate in the selection of a contractor to produce the Voice Switching and Controlling System, a critical element in the NAS Plan.

The new electronic switching system will be faster, more flexible and reliable, and cheaper to maintain than the present electromechanical system, which is based on the technology of the 1950's. The new system will provide controllers at air route traffic control centers with computer-controlled voice switching for air-ground communications as well as intercom

and interphone communications within and between FAA facilities. The contracts allow 35 months for the development of prototypes; and the winner of the competition will produce and install 25 systems.

Airport Visual Aids and Lights

The FAA continued to investigate ways to standardize instrument flight rule approach lighting systems for heliports. The FAA Technical Center and NASA's Langley Research Center evaluated prototype lighting systems using actual weather and simulation flights. Testing will continue at the Technical Center, and a system is expected to be operational before the first commercial IFR heliport is established in the United States.

Also, the agency continued to investigate taxiway visual guidance devices that reduce the frequency of inadvertent runway instruction. A joint FAA-industry working group was convened to address this problem. Remedies suggested by the working group were evaluated at the Technical Center.

In a related effort, the FAA evaluated newly developed runway lighting systems, requiring no external power source, that use tritium-powered, self-contained radioluminescent lights. One of the systems evaluated consisted of runway edge lighting units, threshold lighting units, an airport identification beacon, and a lighted wind direction indicator. The system provided satisfactory visual cues only under the most favorable climatic conditions, and without background lighting. Therefore, its potential use is limited to remote areas not affected by city night lights.

New York TRACON

In March 1986, a contract was awarded to improve the automated air traffic control system at the New York Terminal Radar Approach (TRACON) facility. The New York TRACON provides radar service to aircraft approaching or departing three major airports and 40 satellite airports in the New York metropolitan area. It is the largest facility of its kind in the FAA air traffic control system, handling more than 1.5 million flights annually. Improvement of the system is necessary to allow the TRACON to keep abreast of increasing traffic growth.

Currently, the TRACON is equipped with a standard automated radar terminal system known as ARTS IIIA, a real-time computer system that processes data from remote radar sites and presents it, in alphanumeric form, directly to controllers' radar displays. The displayed information included aircraft identification, altitude, and ground speed. The enhanced system, known as ARTS IIIE, and the only one of its kind, will perform the same functions but will have a greater capacity. When completed, it will be capable of tracking 2,800 aircraft at one time within a 15,000 square mile area.

Office of Commercial Space Transportation

One of the major consequences of the Challenger tragedy was the President's decision to take the Shuttle out of the business of launching routine foreign and commercial satellites. This decision, announced in August 1986, was later incorporated into the U.S. Space Launch Strategy, which called for a space transportation system composed of both ELV's and the Space Shuttle. The factors contributing to a mixed fleet strategy included a significant backlog of payloads, a dramatically reduced flight rate, new operating rules imposed in response to the recommendations of the Presidential Commission on the Space Shuttle Challenger Accident, and the added cost of orbiter design and replacement. The revised space launch strategy emphasized that the Shuttle fleet would be used for missions requiring its unique capabilities, and that the commercial expendable launch vehicle industry would be a critical element in meeting Government and industry needs. Indeed, the Air Force insisted that the winner of the Medium Launch Vehicle competition demonstrate commercial adaptability as part of its proposal.

Complementing Government policy changes aimed at creating a positive environment for commercial ELV's, the Office of Commercial Space Transportation developed regulatory guidance and interagency relationships for this important initiative. Meetings were held with domestic launch firms, satellite manufacturers, and owners and operators to ascertain the potential effect of various public options on their business operations.

The Department of Transportation (DOT) was an active participant in both the National Security Council's Senior Interagency Group on Space and the Economic Policy Council's (EPC) Commercial Space Working Group. These groups developed policy positions and draft language for the President's August 15 decision regarding a replacement orbiter and Shuttle use for commercial and foreign payloads, and for DOD's procurement of additional ELV's. Also, the Department worked closely with other executive agencies to develop a transition plan for payloads that would no longer fly aboard the Shuttle.

The Department also participated in Cabinet-level efforts to identify impediments to space commercialization by chairing an EPC Working Group subcommittee on insurance. In this capacity, it evaluated the availability of private sector launch insurance and third-party liability insurance as they affect space commercialization. During 1986, the Office's Director delivered testimony on the insurance issue before two House and Senate subcommittees.

The President's National Commission on Space. The Office of Commercial Space Transportation participated as an ex-officio member of the National Commission on Space and contributed to its report, "Pioneering the Space Frontier." The Department's participation primarily involved issues related to the private sector's role in next-generation space transportation systems. Also, it contributed to the transportation systems architecture study on future launch vehicles conducted by DOD and NASA.

Use of Government Facilities and Services. The Office of Commercial Space Transportation assists commercial launch firms by helping them gain access to national launch facilities and services. In 1986, DOT worked closely with DOD and NASA to develop the policy guidance and establish the terms and conditions that will govern commercial launch operations on Government ranges. As a result of close cooperation among all three agencies, American Rocket Company was able to use the Air Force's Rocket Propulsion Laboratory facilities at Edwards Air Force Base to conduct tests of its hybrid rocket engine. In August 1986, NASA signed an agreement with Space Services, Inc. authorizing that company's use of the Wallops Island launch facility.

Liaison with the Commercial Space Industry. Significant effort was devoted to main-

taining productive working relationships with all segments of the commercial space industry. DOT representatives met with members of the financial community to clarify and reinforce the Government's commitment to commercialization of space. In addition, working relationships were established with representatives of the communications industry to determine the factors shaping demand for communications satellites. Efforts were made to determine launch firms' need for communications services to support tracking, telemetry, and control.

Commercial Space Transportation Advisory Committee (COMSTAC). The Advisory Committee's members are appointed by the Secretary of Transportation, and include representatives from the major aerospace manufacturers, satellite communications firms, the financial, investment and legal communities, and entrepreneurial launch companies. Two meetings of COMSTAC were held to ensure that the Department had a complete, accurate overview of the issues facing the space business community.

This year, COMSTAC focused on launch and third-party liability insurance and its effect upon financing commercial space ventures, upon capital formation, and upon the development of DOT's regulatory framework. Briefings were also presented on impediments to space commercialization, on commercial launch firms' activities in response to increased demand after the Challenger accident, and on initiatives undertaken by aerospace firms in the Houston area.

Regulatory, Technical, and Safety Activities. In 1986, the Department directed much of its effort toward establishing an efficient procedural framework for regulating commercial launch activities. While publishing regulations in the *Federal Register* and issuing licenses are highly visible actions that can be used to measure progress, these actions are actually the product of an intense, behind-the-scenes effort to implement legislation as important and sweeping as the Commercial Space Launch Act. Thus, regulatory development and research in 1986 began with the previous year's policy statement outlining general concepts for a launch licensing process.

In order to manage an effective licensing program, the Department developed specific, step-by-step administrative procedures, licensing policies, mission and safety review procedures and criteria, and information requirements. This effort was conducted with

14 agencies that included the Occupational Health and Safety Administration, Environmental Protection Agency, and the Nuclear Regulatory Commission, along with agencies directly involved in the space program such as NASA, DOD, and Commerce. Interim regulations were published in February 1986, with an invitation for public comment. The public comments they generated generally were favorable, and will result in the publication of final regulations in early 1987. These regulations will provide guidance to any commercial launch company, operator of a private launch site, or operator of an unlicensed payload applying for a Government review and safety determination.

Administration policy requires that all regulations that affect the private sector be assessed to determine the impact they will have upon public safety, and upon the industry's economic health and chance for survival. In some instances, DOT's interim final launch licensing regulation will require that a firm provide substantial data demonstrating the safety of its activity. In compliance with Executive Order 12291 and internal Department policies, DOT prepared an impact assessment of the new regulation. It concluded that the benefits of these policies outweighed the potential cost to the industry and the Nation. Like the draft regulation, the impact assessment was available for public comment.

The Commercial Space Launch Act charges the Department of Transportation with responsibility for establishing minimum requirements for third-party liability insurance, which commercial launch operators must carry. Third-party liability insurance protects the Government from having to pay damages should a third party, such as persons or property not directly involved with the launch operation, be hurt or otherwise damaged as a result of the launch. In 1985, the Department issued an advance notice of proposed rulemaking (ANPRM) requesting public comment on a variety of mechanisms to implement the Department's authority in this area. To answer the extensive probing and complex questions that resulted from the ANPRM, the Department researched issues germane to third-party liability insurance requirements.

Environmental Assessment. The National Environmental Policy Act requires that major Federal actions be assessed for their effects upon the environment. Clearly, issuing regula-

tions that govern the activities of a new industry constitutes a major Federal action. Because commercial launches are expected to be routine events, their environmental effects had to be assessed prior to issuing regulations under which they would operate. The effects of commercial launches on air quality, water quality, noise levels, and land uses were evaluated by using information about unmanned space launches conducted over the last 20 years. In February 1986, this evaluation was published as a programmatic environmental assessment, and made available for public review and comment.

The environmental assessment represents a major milestone in commercial space transportation. The only response to the assessment that the Department received was a finding by the Environmental Protection Agency that there appeared to be no significant impacts, and, in September, the Department issued a "Finding of No Significant Impact." Although no significant environmental impacts are expected from the development of the industry, or from the conduct of routine launch operations, there may be launch-peculiar aspects that will have to be addressed during the licensing review process.

Safety Research and Technical Program Development. One of the most challenging aspects of the Department's charter is ensuring that no aspect of commercial launch activities poses unreasonable risks to public safety. In order to develop appropriate safety requirements, DOT conducts analyses and studies of the same scope and depth as those conducted in other modes of transportation. The Department has planned a research program that will examine methodically safety issues involved in commercial space launch activities. The research will not duplicate efforts of NASA or the Air Force, but will build upon the existing knowledge base, as DOT does now in the area of aviation. Commercial space launch research will concentrate in areas that include risk management, commercial payload effects on the space environment, commercial ground and flight safety, safety equipment requirements, and commercial safety operating procedures.

Encouraging commercial investment in space transportation remains a U.S. Government priority. In 1983, when the President first requested the Government and the private sector to make the development of a robust commercial launch industry a national goal, significant barriers were encountered.

An efficient launch approval process had to be devised, and disincentives to investment, such as U.S. Government competition in the commercial launch market, removed. Today, those barriers have largely been removed. The Department of Transportation has made substantial progress in encouraging and facilitating the development of this new industry, and has established the foundation for commercial success in the space frontier.

Environmental Protection Agency

The Environmental Protection Agency (EPA) cooperated with NASA in developing and applying a number of aerospace technologies that include a geographic information system for monitoring the environment and factors that affect it; laser technology for the remote measurement of airborne pollutants and water quality; mathematical models for acid deposition studies; the use of high-altitude photography in support of provisions of the Resource Conservation and Recovery Act (RCRA) relating to waste-site location, permit writing, site analysis, enforcement activities, and the underground storage tank program. Aerial photography is also used to support waste-site investigations conducted under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), also known as Superfund.

Monitoring and Assessing the Environment

Geographic Information Systems

Geographic Information Systems (GIS) provide a means for computerized manipulation of multiple data sets from or related to Landsat satellites, photography, topography, land use, vegetation, soils, weather, population distribution, geology, and sampling locations for monitoring and assessing the environment. The locations of spatially variable information are organized and referenced using cartesian (x,y) coordinates and grid cells. The information is then retrieved by subject (such as land use, soil type, and water well location) and manipulated, combined, and displayed as complex geographic data bases. Processing and manipulating the GIS data base through various computer operations result in a series of thematic overlays describing many environmental variables that relate to a particular site or region. Applications for the overlays include hazardous waste permit analysis, local and regional environmental impact assessment, monitoring systems design, and compliance monitoring.

Acid Deposition Studies

NASA and EPA are developing methods to model acid deposition from the Philadelphia metropolitan area. This area can be visualized as an 80- to 100-kilometer square containing a large number of individual sources of pollutants such as sulfur dioxide, hydrocarbons, and the oxides of nitrogen. The purpose of the modeling study is to characterize how the pollutants affect the chemical composition of rainfall reaching the ground in the first few hundred kilometers downwind of the sources. It will compare results of calculations using mathematical models of meteorological and chemical processes with the results of field observations.

The mathematical models are of two types. First is a meteorological model called the Mesoscale Atmospheric Simulator Model (MASS) developed for Langley Research Center. This model was tested by the Goddard Space Flight Center and provided an excellent simulation of the weather. The second model, the Sulfur Transport Eulerian Model (STEM), was developed jointly by the Universities of Iowa and Kentucky with financial support from NASA and EPA. Both models run on Langley's computers and represent the state of the art in their respective disciplines.

Since the study's inception in March 1985, meteorological conditions for three experimental periods were simulated successfully. The simulations are necessary because the atmosphere at levels above the surface is observed only at 12-hour intervals, and at stations approximately 400 kilometers apart. Calculations of meteorological conditions with the models yield resolutions that are more detailed than those obtained from observations alone.

Once the meteorological fields have been calculated, STEM performs the functions of modeling the chemical transformations occurring in the atmosphere, the transporting of the various chemical species, and the removal of the species by rain. Both STEM and MASS are designed to simulate field experiments and to analyze major processes contributing to acid deposition on a mesoscale basis. The field results from the EPA experi-

ments indicate that nitrate deposition resulting from urban-industrial sources can be very significant. The models are designed to determine the origin of nitrates from several sources, such as automotive emissions and petrochemical processing emissions, and then comparing calculated results. In this way, the models and field efforts are mutually supportive.

High-Altitude Photography

The Resource Conservation and Recovery Act requires states to inventory open dumps and landfills associated with municipal and industrial activities. Similar inventories of surface impoundments are required under the Clean Water Act. These inventories help states determine and control the effects of seepage, drainage, and plumes from surface impoundments, landfills, and open dumps.

To support state efforts, scientists from EPA acquire and analyze aerial photographs, obtained by NASA U-2 flights, to help locate and inventory hazardous waste sites. Aerial photography provides an accurate and cost-effective way to supplement other sources of information, such as industrial directories, government records, thematic and topographic maps, and letter surveys that may provide only partial information, or may be out of date. The aerial photographic inventories serve as a basic guide to sites and provide general identification and descriptions.

In one application, specialists were able to acquire high-altitude aerial photographs covering the State of Pennsylvania, about 48,000 square miles, in 8 hours of flight time. The photographs located approximately 3,500 landfills and dumps and several times as many impoundments in the state. Similarly, Gulf Coast areas of Mississippi, Alabama, and Florida, about 21,000 square miles, were photographed from high altitude with a conventional mapping camera in less than 9 hours of flight time. These photographs allowed identification of over 600 waste sites. Sites are classified according to the kind of facility associated with them, such as industrial, municipal, agricultural, mining, oil or gas, sewage treatment, and land disposal.

Aerial Photographic Septic Tank Assessments

The Clean Water Act authorizes the funding of sewage collection and treatment facili-

ties. During the implementation of this legislation in areas serviced by septic systems, EPA recognized the need to document the condition of these systems. Unfortunately, available field survey methods have technical limitations, and public records are usually incomplete. Therefore, researchers at EPA have developed aerial photographic techniques to help identify failures in septic systems.

An area under study is photographed using both color infrared and standard color photography at a scale of 1:8,000. This scale provides the necessary resolution while allowing enough area coverage to make the method cost-effective. The color infrared imagery is the primary source for interpretation because of its ability to detect subtle changes in vegetative growth patterns. The standard color photography is used primarily for comparative purposes.

The analyst uses high-powered optics and stereoscope to examine each lot in the study area for signs of unusual vegetative growth, plant foliage stress, and excessive soil moisture levels. Growth-stress-depth vegetative patterns associated with upward or lateral movements of septic system effluent appear different from the surrounding vegetation on both standard color and color infrared photography.

Analysts also can identify secondary indications of septic system failures. Indicators of such failures may be small ditches or trenches constructed by home owners to remove the effluent from failing systems, small hoses or pipes to reroute wash water from an overloaded system, and coverings of an impervious material such as clay.

Aerial Photography for RCRA/CERCLA

Remote sensing projects support the process of issuing permits for facilities, site analysis, and enforcement activities under provisions of the Resource Conservation and Recovery Act (RCRA); and site operations monitoring, topographic and flood mapping, demographic change analysis, and the Underground Storage Tank program. Aerial photography is also the most commonly used remote sensing technique for supporting waste-site investigations conducted under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), often called Superfund. The prin-

cial aerial photographic system used is the 9" x 9" mapping camera. Color and color infrared films are most frequently used because these media provide enhanced differentiation of subtle spectral characteristics associated with such features as surface leachate, surface water turbidity, soil moisture, and vegetation stress. Various types of aircraft are used at different flight altitudes. Archival aerial photography provides a valuable source of information for the historical analysis of hazardous waste sites and is routinely used. Moreover, image analysts who interpret aerial imagery are fully qualified to provide expert witness testimony on the analysis findings.

EPA conducts four basic types of remote sensing under RCRA or CERCLA. First, priority is given to emergency response projects under hazardous material release situations requiring rapid assessment of conditions at a site. When current information on a site is required, the practice is usually to acquire new photography. Data analysis may be conducted on this new imagery or on historical imagery taken during a particularly significant period in the history of the site. Second, intensive site-analysis projects are performed on selected sites to document changing conditions over a period of time. Third, waste-site inventories are conducted over large areas to establish a baseline reference of sites. In addition, a number of special purpose products are produced using more advanced technologies to process photographic data. Fourth, photogrammetry is employed to produce detailed topographic maps of waste sites. As an expansion of the applications of photogrammetry, flood-plain maps defining the 1 in 25, 1 in 50, and 1 in 100-year flood plain are developed for hazardous waste sites. This effort involves combining topographic data derived from photogrammetry with hydraulic or stream-flow data sets.

National Science Foundation

The National Science Foundation (NSF) supports research in both the astronomical and atmospheric sciences. In 1986, NSF supported ground-based and theoretical astronomy that included five grant programs benefiting more than 140 universities and three National Astronomy Centers.

In the atmospheric sciences, NSF provides the primary support for research by universities, and both nonprofit and profit-making groups in the United States. It also supports the National Center for Atmospheric Research (NCAR) and the Upper Atmospheric Facilities (UAF) program. In collaboration with the atmospheric sciences community, NCAR conducts large scientific research programs, and offers use of major facilities that would be beyond the scope of those available at a single university. The UAF supports four incoherent-scatter radar facilities that stretch in a longitudinal chain from Greenland to Peru.

Astronomical Sciences

In 1986, the fastest known spinning binary pulsar was discovered. The pulses are so regular that the possibility exists for using this object as a very precise clock whose accuracy exceeds that of the best terrestrial standards.

In the process of star formation, astronomers observed the stage where the collapsing object is closer to attaining stellar dimensions than anything previously observed. Observations made at radio wavelengths show evidence of a star that has only one-quarter of the mass of the Sun. It is surrounded by a cloud of falling material whose mass continues to increase, indicating that the star might become as massive as the Sun.

In a related area, astronomers have obtained optical evidence of companion white dwarf stars in binary pulsar systems. The highest magnetic field known was measured on the surface of a white dwarf star. The strength of this magnetic field is 700 million times greater than the Earth's magnetic field.

Atmospheric Sciences

In 1986, NSF supported basic atmospheric research on a wide range of subjects, and remains the largest federal supporter of academic research in the atmospheric sciences.

Significant achievements in the atmospheric sciences included modeling of the ice age climate. Reconstructions of climate of the past 20,000 years from paleoecological land records correlated remarkably well with results from the NCAR Community Climate Model.

Basic research on the physics of cirrus clouds will allow a better understanding of the absorption, reflection and transmission of solar and terrestrial radiation by these clouds in global climate models. This is due to the observations of liquid water in cirrus clouds, previously thought to consist entirely of ice crystals.

Researchers have established that the solar flux increased from the solar cycle maximum in 1968 through 1969 to the solar cycle maximum from 1978 through 1979, and, subsequently, decreased to the present time. The solar diameter showed the same pattern. This connection is important for understanding climate variations, and for studying the physics of solar activity and variability.

In August, the National Ozone Expedition (NOZE), was dispatched to study the depletion of stratospheric ozone over the Antarctic continent. In addition to NSF, support was provided by NASA, NOAA, and the Chemical Manufacturers Association. Research results should provide a better understanding of ozone depletion over Antarctica.

Smithsonian Institution

The Smithsonian Institution contributes to the Nation's space goals through basic research programs at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, Massachusetts, and through public exhibits, lectures, and educational programs at the National Air and Space Museum (NASM) in Washington, D.C. NASM's Center for Earth and Planetary Studies (CEPS) also conducts basic research in planetary geology and terrestrial remote sensing.

Space Sciences

High-Energy Astrophysics

Using a combination of satellite and ground-based observations, SAO scientists discovered a possible third black hole in the Milky Way. The technique used—observing its visible light counterpart—can be applied to the search for additional objects of this type.

The continued reduction and analysis of data from the HEAO-1 and HEAO-2 (Einstein) satellites led to the discovery of a cool, high-density, x-ray-emitting gas in the central regions of some galaxies. As this gas continues to cool, it condenses to form new stars; thus, these "old" galaxies still show activity characteristic of younger galaxies.

Quasars, extremely luminous objects located at the core of some galaxies, emit x-rays with a universal signature which allows an efficient way to locate them. This is important for understanding the development of certain properties of the universe over the past 15 billion years.

Infrared Astronomy

Maps of the infrared sky were produced from data obtained by a helium-cooled infrared telescope (IRT) carried on the flight of Spacelab 2 in July 1985. Although hampered by significant background contamination associated with the Shuttle environment, the IRT successfully traced diffuse infrared radiation from the plane of the Milky Way in wavebands previously unrecorded. Properties

of large volumes of superfluid helium in space also were measured.

Atmospheric Sciences

The chemistry of Earth's stratosphere was studied by means of far-infrared spectra obtained from a balloon-borne telescope. The most significant result of this research was the first detection of stratospheric hydrogen peroxide.

Space Technology

After more than a decade of work, SAO and Harvard University scientists succeeded in operating an atomic maser clock to within one-half degree of absolute zero. At that temperature, it is anticipated that the "cold clock" will be one thousand times more accurate than any other time standard yet developed. The new clock could be used in a variety of experiments in space.

Planetary Sciences

SAO scientists were among many involved in Halley's Comet research, including international efforts to achieve a close fly-by of the Comet, and to measure the physical characteristics of its nucleus. The measurements confirmed the "dirty snowball" model of a comet's nucleus that was developed by an SAO scientist.

Voyager spacecraft data show Saturn's outermost ring to be curiously uneven in brightness, with two bright regions 180 degrees apart separated by two darker regions. Research indicates that this irregularity is caused by a tendency of particles to cluster gravitationally in aligned arrays that reflect light better in one direction than in the direction perpendicular to it.

SAO continued its study of lunar samples. In particular, collaborative research was undertaken with other institutions on rocks taken from the Apollo 16 site. Located in the Moon's central highlands, this site contains complex layers of debris, splashed there by giant impacts that created large lunar basins approximately 3.9 billion years ago. SAO studies suggest the impact that formed the Imbrium basin occurred 50 million years earlier than previously thought, providing a more accurate chronology of the Moon's early history.

Using Viking Orbiter images taken in different color filters, CEPS researchers isolated discrete areas of the Martian terrain that indicate much of the northern smooth plains of the planet formerly were underlain by ancient crust, which is now only visible in the southern hemisphere. Currently, image processing techniques are being used to reconstruct evolution of the northern smooth plains from an early period of intense meteoritic bombardment to the most recent deposition of fluvial sediments.

In 1986, a comparative study of the basalt plains on Mars and Earth began. The Thematic Mapper Camera aboard Landsat provided images of structural features in the Columbia Plateau. This information was compared to images of similar features on Mars taken by the Viking Orbiter. This research is particularly valuable because field work on the Columbian ridges could result in validation of theories on their origin.

Changes in Earth's desert regions, caused by sand transport and different uses of arable soil, are being monitored through a study of orbital images. The research is concentrated on southern Egypt, where dune migration has overtaken the landscape, and Mali, where visible land-use patterns indicate areas prone to active erosion. The long-term goal is to determine what can and cannot be learned from medium- and high-resolution spectral imaging of Earth's arid regions.

Department of State

The role of the Department of State in the U.S. civil space program is to evaluate space programs, policies, and agreements in the context of advancing U.S. foreign policy interests. It advises the President on international space matters, is the principal negotiator of government-to-government agreements, and represents the United States in international organizations involved in space.

In 1986, the United States continued to negotiate with international partners on the permanently manned Space Station. In close cooperation with NASA and other interested agencies, Department officials met with European, Japanese, and Canadian representatives to negotiate government-to-government agreements on the detailed design, development, operation, and utilization of the Space Station. This activity builds upon Memoranda of Understanding signed in 1985, and signifies progress in making the largest international space project in history a reality. The Department of State strongly supports the Space Station as a concrete demonstration of U.S. leadership in space, as a stimulus for exploring new areas of science and technology, and as a positive model for international cooperation and mutual benefit.

In 1986, the Department played a major role in interagency discussions on a number of space policy issues. The Challenger tragedy resulted in a re-evaluation of the entire U.S. civil space program, changed U.S. commercial space policy, and radically altered plans for world satellite launches. Each of these areas affected international space policies, and national policies of countries that have cooperative space projects with the United States or depend on it for launch services. As the agency responsible for representing U.S. foreign policy interests in the international arena, the Department of State actively participated in discussions of these issues, conveying and evaluating foreign country viewpoints and explaining U.S. decisions.

The Department of State continued to represent the United States in international bodies involved in space issues. One of the principal forums is the United Nation

(UN) and its Committee on the Peaceful Uses of Outer Space (COPUOS).

Activities Within the United Nations

Committee on the Peaceful Uses of Outer Space

The 53 member COPUOS was established in 1958 by the UN General Assembly to promote international cooperation in the exploration and peaceful uses of outer space. For 20 years it served as a productive vehicle for the exchange of scientific information. It was also responsible for negotiating four widely accepted UN conventions that form the basis of international space law.

In recent years, however, the scientific and legal work of the Committee have seriously deteriorated. Debates were influenced by extraneous political factors, and there was an increasing tendency to involve the Committee in disarmament and political issues outside its mandate. As the 39th session of the UN General Assembly, the United States and other Western nations attempted to arrest the decline by making a number of changes in the agenda of COPUOS and its Subcommittees. During 1985 and 1986, Western states continued their efforts to restore scientific and technical utility to the work of COPUOS and to make it function in accordance with its original mandate.

In February 1986, the Scientific and Technical Subcommittee adopted a U.S./Western proposal to add planetary exploration and astronomy to its agenda. This was one of many proposals that Western nations made in an effort to arrest serious deterioration in the Subcommittee's scientific work. The Subcommittee rejected an Eastern bloc proposal to add new items to the agenda that focused largely on the disarmament position of the Soviet Union.

In March 1986, the Legal Subcommittee endorsed the Austrian draft text "Principles Relating to Remote Sensing of the Earth from Outer Space." Modeled on policies and practices instituted years ago by the United States, the principles encourage the public,

Communication Satellites

non-discriminatory availability of data, and promote opportunities for international participation in national remote sensing programs. COPUOS endorsed the draft text; subsequently, it was presented to the 41st Session of the UN General Assembly.

During its 29th plenary session in June 1986, COPUOS agreed to include life science research, astronomy, and planetary science in the 1987 agenda of the Scientific and Technical Subcommittee. COPUOS also accepted a Latin American proposal to establish a Working Group of the Whole for the 1987 meeting of the Scientific and Technical Subcommittee that will evaluate the implementation of the Unispace '82 recommendations. That proposal was similar to one recommended by the West in 1985. The U.S. and Western delegations continued to press for measures to review the organization and working methods of COPUOS and its Subcommittees, without much success, to date.

UN General Assembly (UNGA)

On the recommendation of the Special Political Committee, the 41st session of the UN General Assembly adopted the omnibus resolution "International Cooperation in the Peaceful Uses of Outer Space." The resolution sets the agendas of COPUOS and its Subcommittees for 1987, and reflects several proposals the U.S. and other Western states had offered in 1986 to re-establish the scientific and technical content of the Committee's work. The UNGA also adopted the draft text "Principles Relating to Remote Sensing of the Earth from Outer Space" that was forwarded by COPUOS. Pursuant to Article X of the Convention on the Registration of Objects Launched into Outer Space, the UNGA also conducted a review of that instrument to determine whether it required revision. The UNGA determined that the Convention works satisfactorily, and urged non-signatory states to consider becoming parties to it.

In the 41st session of the UNGA, the U.S. reiterated its concerns over the unwillingness by many member states to consider the need to make COPUOS and its Subcommittees more efficient and effective, and expressed its disappointment that COPUOS had not yet acted on other proposals that Western states had presented in an effort to revitalize it.

International Telecommunication Union (ITU)

The United States prepared for the ITU's World Administrative Radio Conference for Mobile Services (Mobile WARC) that will be held in Geneva, Switzerland in September and October 1987. The conference will review and revise regulations for mobile services from terrestrial and satellite communications, radio determination and radio navigation satellite systems. In July, at a special meeting held in Geneva, a draft of the U.S. technical proposals was presented to 41 countries.

In September, the ITU's International Frequency Registration Board unanimously adopted a report that identified and documented 37 frequencies of the Voice of America, Radio Liberty, and Radio Free Europe that were jammed by the Soviet Union, Czechoslovakia, and Poland. This is the first official technical body within the UN system to recognize this violation of obligations under the ITU's Radio Regulations and the Helsinki accords.

In May, the ITU's International Radio Consultative Committee submitted to the Plenary Assembly a U.S. recommendation for worldwide High Definition Television (HDTV) standards for the studio and for international program exchange. This position was developed by the Advanced Television Systems Committee, a voluntary organization of U.S. industry, established in 1983. However, a coalition of EEC members, primarily concerned with protecting the interests of the European electronics industry, was instrumental in effecting a two-year postponement of any decision to adopt worldwide HDTV standards.

International Communications Satellite Organization (INTELSAT)

In December 1986, the INTELSAT Board of Governors approved a U.S. proposal to establish the first international satellite communications system separate from INTELSAT. Also, in 1986, following its 1985 decision to provide domestic services, INTELSAT concluded several sales and lease agreements. In addition to international communications, it now offers domestic services, particularly to developing countries.

*International Maritime Satellite
Organization (INMARSAT)*

Member states began ratifying the 1985 amendments to the INMARSAT convention that will allow aeronautical communication services. While several countries have ratified the amendments, the U.S. has taken them under advisement. In the meantime, work continues on defining technical requirements and tariff structures for the services.

Arms Control and Disarmament Agency

The United States Arms Control and Disarmament Agency (ACDA), established in 1961 to advise the President of the United States on arms control policy, plays a key role in the development and support of that policy. Historically, ACDA has paid considerable attention to arms control in outer space. With increased emphasis placed upon the potential use of space, the role of ACDA has grown in importance.

U.S. Space Arms Control Activities

President Reagan outlined the National Space Policy July 4, 1982. In his remarks, he said:

The United States will continue to study space arms control options. The United States will consider verifiable and equitable arms control measures that would ban or otherwise limit testing and deployment of specific weapons systems, should those measures be compatible with United States national security.

The President reaffirmed that policy on March 31, 1984 in a report to the Congress on anti-satellite (ASAT) arms control.

During the past two years, ACDA has been deeply involved in the Nuclear and Space Talks, a bilateral U.S.—Soviet arms control negotiation that began in March 1985. In January 1985, at a meeting between Secretary of State Shultz and then Soviet Foreign Minister Gromyko, it was agreed that these talks would be composed of three separate groups, one of which addresses defense and space issues. In this forum, called the Defense and Space Negotiating Group, ACDA has continued to analyze and articulate the U.S. position on space arms control.

Multilateral Discussions on Space Arms Control

ACDA continues to pursue U.S. space policy objectives in two multilateral forums each year: the United Nations General Assembly

and its First Committee, and the Conference on Disarmament (CD) in Geneva, Switzerland. In March 1985, the CD established an *ad hoc* committee to examine issues relevant to the prevention of an arms race in outer space. The United States and its allies support the work of this specialized committee, which has a non-negotiating mandate to address space arms control issues, to review the current legal regime of space, and to discuss existing and future proposals.

Space Policy

ACDA is involved extensively in the formulation of U.S. space policy. For example, the agency co-chairs the Interagency Group on Defense and Space, which addresses space arms control issues. Also, it is a member of the interagency group that defines U.S. policy on the Strategic Defense Initiative (SDI). In addition, ACDA provides administrative support, senior representatives, advisors, and legal experts to U.S. arms control negotiations.

The agency participates in the Senior Interagency Group on Space that addresses a range of issues involving space, such as development of the manned U.S. Space Station. There are a number of other interagency groups in which ACDA participates that review topics relative to space, such as bilateral governmental space activities and cooperation, and the sale of space-related items. Also, ACDA contributes to U.S. consideration of technical collection assets for verifying compliance with arms control agreements; these include space-based assets that are part of the national technical means of verification.

United States Information Agency

As part of its continuing coverage of American achievements in science and technology, the United States Information Agency (USIA) devotes considerable attention to the U.S. space program. To tell its story to the world, USIA uses such communication techniques as radio programs, newspaper stories, direct satellite TV broadcasts, exhibits, and overseas visits by scientists and astronauts.

Voice of America

In 1986, a major subject of news programs of the Voice of America (VOA) was the accident of the Space Shuttle Challenger. VOA's English and foreign language broadcasts provided full and objective coverage of the disaster, and attempted to place it in its proper context within the U.S. space program.

Among other topics meriting in-depth news coverage were: Voyager 2's encounter with Uranus, the appearance of Halley's Comet, the future Space Station, remote sensing satellites, and the Report of the National Commission on Space. Most of VOA's 41 foreign language services covered stories in these areas. The fact that VOA continually receives inquiries on these topics by overseas audiences is an indication of the high interest in the U.S. space program.

Television Service

Worldnet, USIA's popular satellite telecast service, generated a steady stream of news and features on the U.S. space program. Worldnet's news magazine, *America Today*, focused on events such as the Voyager 2 mission, the Challenger accident, the Young Astronauts Program, and the future Space Station. Worldnet also carried live interviews, via satellite, between NASA officials, U.S. space experts, and foreign journalists and scientists. For example, NASA's Administrator, Dr. James Fletcher, discussed the space program with newsmen in Bern, Brussels, Paris, and Rome.

In other activities, the Satellite File, a weekly series of TV clips, distributed many items about NASA to 120 countries; the TV acquisition program sent a large number of

video tapes on space topics to USIS posts abroad, including a 17-part series entitled "NASA at Work." Many of the video tapes were broadcast by overseas TV stations, while others were shown to large audiences at various locations.

Other USIA Activities

USIA's Press and Publications Service provided USIS posts abroad with a variety of information for placement in the local media, post publications, and for background use. The Wireless File, which serves 213 posts in 128 locations, provided full and accurate coverage of the Challenger accident, along with statements by the President, and others, emphasizing America's determination to continue its pursuit of a vigorous space program. Articles on space exploration highlighted the many benefits to be derived through international cooperation.

America Illustrated, USIA's monthly Russian-language magazine which is distributed in the Soviet Union, published an illustrated feature on Voyager 2's encounter with Uranus. USIA's Foreign Press Centers in Washington and Los Angeles offered briefings on the space program, and assisted resident and visiting correspondents from overseas news organizations.

USIA worked closely with NASA in the development and operation of the American Pavilion at Vancouver's Expo '86. The Pavilion focused on space exploration and transportation, and, in particular, on the manned Space Station proposed for the 1990's and beyond. A number of American and Canadian astronauts visited the Pavilion, which was one of the most popular at the fair.

In 1986, the American Participant Program sponsored trips abroad for two astronauts; both received extensive and favorable news coverage. Jon McBride visited Indonesia, and participated in the opening of a major international air show. Dr. Franklin Chang-Diaz traveled on two separate programs. His first trip was to Argentina, Uruguay, Chile and Venezuela; his second journey was to Malaysia, where he participated in the ASEAN Science Symposium.

Appendixes

APPENDIX A-1

U.S. Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

Calendar Year	Earth Orbit ^a		Earth Escape ^a		Calendar Year	Earth Orbit ^a		Earth Escape ^a	
	Success	Failure	Success	Failure		Success	Failure	Success	Failure
1957	0	1	0	0	1972	33	2	8	0
1958	5	8	0	4	1973	23	2	3	0
1959	9	9	1	2	1974	27	2	1	0
1960	16	12	1	2	1975	30	4	4	0
1961	35	12	0	2	1976	33	0	1	0
1962	55	12	4	1	1977	27	2	2	0
1963	62	11	0	0	1978	34	2	7	0
1964	69	8	4	0	1979	18	0	0	0
1965	93	7	4	1	1980	16	4	0	0
1966	94	12	7	1 ^b	1981	20	1	0	0
1967	78	4	10	0	1982	21	0	0	0
1968	61	15	3	0	1983	31	0	0	0
1969	58	1	8	1	1984	35	3	0	0
1970	36	1	3	0	1985	37	1	0	0
1971	45	2	8	1	1986	11	4	0	0
Total					1,112	142	79	15	

^aThe criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from the Earth.

^bThis Earth-escape failure did attain Earth orbit and therefore is included in the Earth-orbit success totals.

APPENDIX A-2

World Record of Space Launches Successful In Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)

Calendar Year	United States	U.S.S.R.	France	Italy	Japan	People's Republic of China	Australia	United Kingdom	European Space Agency	India
1957		2								
1958	5	1								
1959	10	3								
1960	16	3								
1961	29	6								
1962	52	20								
1963	38	17								
1964	57	30								
1965	63	48	1							
1966	73	44	1							
1967	57	66	2	1			1			
1968	45	74								
1969	40	70								
1970	28	81	2	1 ^a	1	1				
1971	30	83	1	2 ^a	2	1		1		
1972	30	74		1	1					
1973	23	86								
1974	22	81		2 ^a	1					
1975	27	89	3	1	2	3				
1976	26	99			1	2				
1977	24	98			2					
1978	32	88			3	1				
1979	16	87			2				1	
1980	13	89			2					1
1981	18	98			3	1		2		1
1982	18	101			1	1				
1983	22	98			3	1		2		1
1984	22	97			3	3		4		
1985	17	98			2	1		3		
1986	6	91			2	2		2		
Total	859	1,922	10	8	31	17	1	1	14	3

^aIncludes foreign launches of U.S. spacecraft.

Successful U.S. Launches—1986

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Jan. 12 Space Shuttle Columbia (STS-61C) 3A	Objective: To launch RCA Satcom K-1, and conduct experiments. Spacecraft: Shuttle orbiter carrying satellite as well as experiments. Materials Science Laboratory-2 (MLS-2), Hitchhiker G-1, Particle Analysis Cameras for the Shuttle (PACS), Capillary Pump Loop (CPL), Shuttle Environment Effects on Coated Mirrors (SEECM); 12 experiments flown on Get Away Special Bridge Assembly, 1 additional GAS experiment, Infrared Imaging Experiment (IR-IE). Middeck payloads: Initial Blood Storage Experiment (IBSE), and Comet Halley Active Monitoring Program (CHAMP). Additionally 3 Shuttle Student Involvement Program (SSIP) experiments. Weight: 12,708 lbs.	350 327 91.3 28.5	Twenty-fourth flight of Space Transportation System. Piloted by Robert L. "Hoot" Gibson and Charles F. Bolden. Mission specialists Franklin R. Chang-Diaz, Steven A. Hawley, and George D. "Pinky" Nelson. Payload specialists Robert J. Cenker (RCA) and Congressman C. William "Bill" Nelson. Columbia launched KSC 6:55 a.m., EST. Satellite deployed and experiments conducted. Shuttle landed at Edwards AFB, CA, 8:58 a.m., EST, Jan. 18. Mission duration 6 days, 2 hrs, 4 min.
Jan. 12 RCA Satcom K-1 3B	Objective: To successfully launch communications satellite. Spacecraft: Box-shaped, 67 by 84 by 60 inch main structure, three-axis stabilized, twin 280 square ft. solar panels deployed after launch. Weight at launch: 15,929 lbs.	35,794 35,781 1436.2 0.0	Successfully deployed from Columbia, second in series satellite for RCA American Communications, Inc. In orbit.
Feb. 9 Defense 14A Atlas H	Objective: Development of spacecraft techniques and technology. Spacecraft: Not announced.	Not available	In orbit.
Feb. 9 Defense 14E	Objective: Development of spacecraft techniques and technology. Spacecraft: Not announced.	Not available.	In orbit.
Feb. 9 Defense 14F	Objective: Development of spacecraft techniques and technology. Spacecraft: Not announced.	Not available.	In orbit.
Feb. 9 Defense 14H	Objective: Development of spacecraft techniques and technology. Spacecraft: Not announced.	Not available.	In orbit.
Sep. 5 Defense 69A Delta 180	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	719 212 93.9 39.1	Successful launch by NASA for DoD, Strategic Defense Initiative (SDI). Space intercept and collision test. Destroyed.
Sep. 5 Defense 69B	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	611 223 92.9 22.8	Strategic Defense Initiative (SDI) space intercept, and collision test. Destroyed.
Sep. 17 NOAA 10 73A Atlas E	Objective: To launch spacecraft into sun-synchronous orbit of sufficient accuracy to enable satellite to accomplish its operational mission requirements. Spacecraft: Launch configuration: 491 cm high, 188 cm diameter, weight: 1,712 kg.	823 804 101.2 98.7	Third of the advanced Tiros-N series. Funded by NOAA and successfully launched by NASA. Also onboard Search and Rescue instruments. Spacecraft returning data. Still in orbit.

Successful U.S. Launches--1986

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
Nov. 14 Polar Bear 88A Scout	Objective: To launch Air Force P87-1 satellite into an orbit which will enable the successful achievement of mission objectives. Spacecraft: Not announced. Weight: 270 lbs.	1015 960 104.9 89.6	Successfully launched by NASA for the U.S. Air Force. Reconditioned satellite which hung for several years in the National Air and Space Museum. Experiments to study radio interference caused by Aurora Borealis, or Northern Lights. Operating and returning data.
Dec. 5 Fltsatcom 7 96A Atlas-Centaur	Objective: To launch satellite into planned geostationary position. Spacecraft: Hexagonal, composed of payload and spacecraft module; 22.7 ft. high. Provides 1 EHF and 23 UHF communications channels. Weight at liftoff: 5,073 lbs. Weight on orbit: 2,488 lbs.	36,024 35,551 1436.2 5.2	Launched by NASA for Navy, to serve DoD. Still in orbit.

U.S.-Launched Applications Satellites 1980-1986

Date	Name	Launch Vehicle	Remarks
COMMUNICATIONS			
Jan. 18, 1980	Fltsatcom 3	Atlas-Centaur	Third of DoD series.
Oct. 31, 1980	Fltsatcom 4	Atlas-Centaur	Fourth of DoD series.
Nov. 15, 1980	SBS 1	Thor-Delta (TAT)	Launched for Satellite Business Systems as part of its domestic communications links.
Dec. 6, 1980	Intelsat V F-2	Atlas-Centaur	First of new series, positioned over Atlantic.
Feb. 21, 1981	Comstar D-4	Atlas-Centaur	Fourth in series for Comsat General Corp.
May 23, 1981	Intelsat V F-1	Atlas-Centaur	Second in series for INTELSAT, positioned over Atlantic.
Aug. 6, 1981	Fltsatcom 5	Atlas-Centaur	Fifth in DoD series.
Sept. 24, 1981	SBS 2	Thor-Delta (TAT)	Second in series for Satellite Business Systems.
Nov. 20, 1981	RCA-Satcom 3-R	Thor-Delta (TAT)	Fourth in series for RCA, replacement for RCA-Satcom 3.
Dec. 15, 1981	Intelsat V F-3	Atlas-Centaur	Third in series. To be positioned over Atlantic.
Jan. 16, 1982	RCA-Satcom 4	Thor-Delta (TAT)	Fifth in series for RCA.
Feb. 26, 1982	Westar 4	Thor-Delta (TAT)	First in a series of second-generation for Western Union Co.
Mar. 5, 1982	Intelsat V F-4	Atlas-Centaur	Fourth in series; positioned over Pacific.
Apr. 10, 1982	Insat 1A	Thor-Delta (TAT)	First in series for India Department of Space.
June 9, 1982	Westar 5	Thor-Delta (TAT)	Second in series of second-generation for Western Union Co.; replaces Westar 2.
Aug. 26, 1982	Anik D-1	Thor-Delta (TAT)	Launched for Telesat Canada as replacement for in-orbit satellites.
Sept. 28, 1982	Intelsat V F-5	Atlas-Centaur	Fifth in series; positioned over Indian Ocean.
Oct. 27, 1982	RCA-Satcom 5	Thor-Delta (TAT)	Joined 4 operational satellites launched for RCA.
Oct. 30, 1982	DSCS II, DSCS III	Titan III(34) D/IUS	Defense communications (dual launch), including first in series of uprated satellites.
Nov. 11, 1982	SBS 3	Space Shuttle, PAM-D	Third in series for Satellite Business Systems.
Nov. 12, 1982	Anik C-3	Space Shuttle, PAM-D	Second in new series for Telesat Canada.
Apr. 4, 1983	TDRS 1	Space Shuttle, IUS	First in series. System to provide continuous satellite communication. Leased by NASA from Space Communications Co. (Spacecom).
Apr. 11, 1983	RCA-Satcom 6	Delta 3924	Replacement for RCA-Satcom 1, launched for RCA.
May 19, 1983	Intelsat V F-6	Atlas-Centaur	Sixth in series; positioned over Atlantic Ocean.
June 18, 1983	Anik C-2	Space Shuttle, PAM-D	Launched for Telesat Canada.
June 19, 1983	Palapa B-1	Space Shuttle, PAM-D	Indonesian domestic communications.
June 28, 1983	Galaxy 1	Delta 3920/PAM-D	Launched for Hughes Communications, Inc.
July 28, 1983	Telstar 3A	Delta 3920/PAM-D	Launched for American Telephone and Telegraph Co.
Aug. 31, 1983	Insat 1-B	Space Shuttle, PAM-D	Indian domestic communications.
Sept. 8, 1983	RCA-Satcom 7	Delta 3924	Replacement for RCA-Satcom 2, launched for RCA.
Sept. 22, 1983	Galaxy 2	Delta 3920/PAM-D	Second in series, launched for Hughes Communications, Inc.
Feb. 3, 1984	Westar-6	Space Shuttle, PAM-D	Launched for Western Union, PAM-D failed to fire properly, satellite retrieved by Shuttle, and returned to earth for refurbishment.
Feb. 6, 1984	Palapa-B2	Space Shuttle, PAM-D	Launched for Indonesia, booster motor failed, satellite retrieved and returned to earth by Shuttle.
Mar. 1, 1984	Uosat-2	Delta 3920	Secondary payload with Landsat-5; for amateur radio communications.
June 9, 1984	Intelsat V F-9	Atlas-Centaur	Seventh in series, launch vehicle failure, satellite reentered Oct. 24.
Aug. 31, 1984	SBS-4	Space Shuttle, PAM-D	Launched for Satellite Business Systems, Inc.
Aug. 31, 1984	Syncom IV-2	Space Shuttle	Launched for Hughes Communication Service, Inc.
Sept. 1, 1984	Telstar-3C	Space Shuttle, PAM-D	Launched for American Telephone and Telegraph Co.

U.S.-Launched Applications Satellites 1980-1986

Date	Name	Launch Vehicle	Remarks
Sept. 21, 1984	Galaxy-3	Delta 3920/PAM-D	Third in series, launched for Hughes Communications, Inc.
Nov. 9, 1984	Anik-D2	Space Shuttle, PAM-D	Launched for Telesat Canada.
Nov. 10, 1984	Syncom IV-1	Space Shuttle	Launched for Hughes Communication Service, Inc.
Nov. 14, 1984	NATO III D	Delta 3914	NATO defense-related communications satellite.
Mar. 22, 1985	Intelsat VA F-10	Atlas-Centaur	First in series of six improved satellites.
Apr. 12, 1985	Telesat-I	Space Shuttle	Launched for Telesat Canada.
Apr. 13, 1985	Syncom IV-3	Space Shuttle	Launched for US Navy.
June 17, 1985	MORELOS-A	Space Shuttle	Launched for Mexico.
June 18, 1985	Arabsat-1B	Space Shuttle	Launched for Arab Satellite Communication Organization (ASCO).
June 19, 1985	Telstar-3D	Space Shuttle	Launched for the American Telephone and Telegraph Company (AT&T).
June 30, 1985	Intelsat VA F-11	Atlas-Centaur	Second in series of improved satellites launched for INTELSAT.
Aug. 27, 1985	AUSSAT-1	Space Shuttle	Launched for Australia's National Satellite Company.
Aug. 27, 1985	ASC-1	Space Shuttle	Launched for American Satellite Company.
Aug. 29, 1985	Syncom IV-4	Space Shuttle	Launched for US Navy.
Sep. 29, 1985	Intelsat VA F-12	Atlas-Centaur	Launched for INTELSAT.
Nov. 27, 1985	MORELOS-B	Space Shuttle	Launched for Mexico.
Nov. 27, 1985	AUSSAT-2	Space Shuttle	Second satellite launched for Australia's National Satellite Company.
Nov. 28, 1985	RCA Satcom K-2	Space Shuttle	Launched for RCA American Communications, Inc.
Jan. 12, 1986	RCA Satcom K-1	Space Shuttle	Launched for RCA American Communications, Inc.
Dec. 5, 1986	Fltsatcom 7	Atlas-Centaur	Launched for DoD.
WEATHER OBSERVATION ^a			
May 29, 1980	NOAA-B	Atlas F	Failed to achieve useful orbit.
Sept. 9, 1980	GOES 4	Thor-Delta (TAT)	Fourth of this series for NOAA.
May 22, 1981	GOES 5	Thor-Delta (TAT)	Fifth of polar-orbiting series for NOAA.
June 23, 1981	NOAA 7	Atlas F	Replacement for NOAA-B.
Dec. 21, 1982	DMSP F-6	Atlas E	DoD meteorological satellite.
Mar. 28, 1983	NOAA 8	Atlas E	Joined NOAA 7 as part of 2-satellite operational system; launched for NOAA.
Apr. 28, 1983	GOES 6	Delta 3914	Launched for NOAA, operational as GOES-West.
Nov. 18, 1983	DMSP F-7	Atlas E	Second in block 5D-2 series, DoD meteorological satellite.
Dec. 12, 1984	NOAA-9	Atlas E	Launched for NOAA, to replace NOAA-7.
Sep. 17, 1986	NOAA 10	Atlas E	Launched for NOAA.
EARTH OBSERVATION			
July 16, 1982	Landsat 4	Thor-Delta (TAT)	Fourth experimental earth resources satellite. First use of thematic mapper (TM).
Mar. 1, 1984	Landsat-5	Delta 3920	Fifth experimental earth resources satellite, to replace ailing Landsat-4.
GEODESY			
Mar. 13, 1985	GEOSAT	Atlas E	Measure ocean surface height.
NAVIGATION			
Feb. 9, 1980	Navstar 5	Atlas F	Global Positioning System satellite.
Apr. 26, 1980	Navstar 6	Atlas F	Global Positioning System satellite.
May 15, 1981	Nova 1	Scout	First of improved Transit system satellites, for DoD.
July 14, 1983	Navstar 8	Atlas E	Global Positioning System satellite.
Feb. 5, 1984	IRT	Space Shuttle	Balloon to test Shuttle rendezvous radar.
June 13, 1984	Navstar-9	Atlas E	Global Positioning System satellite.
Sept. 8, 1984	Navstar-10	Atlas E	Global Positioning System satellite.
Oct. 12, 1984	Nova-3	Scout	Second of improved Transit system satellites, for DoD.
Aug. 3, 1985	Oscar 24	Scout	Part of Navy Transit System.
Aug. 3, 1985	Oscar 30	Scout	Part of Navy Transit System.
Oct. 9, 1985	Navstar-11	Atlas E	Global Positioning System satellite.

^aDoes not include Department of Defense weather satellites that are not individually identified by launch.

U.S.-Launched Scientific Satellites 1980-1986

Date	Name	Launch Vehicle	Remarks
Feb. 14, 1980	SMM	Thor-Delta (TAT)	Solar Maximum Mission.
Aug. 3, 1981	Dynamics Explorers 1, 2	Thor-Delta (TAT)	DE 1 and 2 to measure magnetospheric-ionospheric energy coupling, electric currents and fields, plasmas.
Oct. 6, 1981	SME	Thor-Delta (TAT)	Solar Mesosphere Explorer to measure changes in mesospheric ozone.
Oct. 6, 1981	UOSAT (Oscar 9)	Thor-Delta (TAT)	Secondary payload with SME, for amateur radio and science experiments.
Jan. 26, 1983	IRAS	Delta 3910	Infrared sky survey.
May 26, 1983	EXOSAT	Delta 3914	European Space Agency study of x-ray sources.
June 22, 1983	SPAS 01	Space Shuttle	Reusable free-flying platform deployed and retrieved during STS 7; 6 scientific experiments from West Germany, 2 from ESA. NASA experiments tested spacecraft technology.
June 27, 1983	HILAT (P83-1)	Scout	Propagation effects of disturbed plasma on radar and communication systems, for DoD.
Apr. 6, 1984	Long Duration Exposure Facility (LDEF-1)	Space Shuttle	Scientific experiments designed for retrieval from space by Shuttle.
Aug. 16, 1984	Charge Composition Explorer (CCE)	Delta 3924	Measurement of earth's magnetosphere, one of three satellites composing Active Magnetosphere Particle Tracer Explorers Mission (AMPTE).
Aug. 16, 1984	Ion Release Module (IRM)	Delta 3924	Second of three satellites of AMPTE Mission, launched by same vehicle.
Aug. 16, 1984	United Kingdom Satellite (UKS)	Delta 3924	Third of three satellites of AMPTE Mission, launched by same vehicle.
Oct. 5, 1984	Earth Radiation Budget Satellite (ERBS)	Space Shuttle	First of three satellites in Earth Radiation Budget Experiment Research Program. NOAA-9 and NOAA-G carrying other instruments in Program.
Apr. 29, 1985	NUSAT-1	Space Shuttle	Northern Utah Satellite (air traffic control radar system calibrator).
June 20, 1985	Spartan-1	Space Shuttle	Reusable free-flying platform.
July 29, 1985	Plasma Diagnostic Package (PDP)	Space Shuttle	Reusable experimental platform.
Oct. 30, 1985	GLOMR	Space Shuttle	Global Low Orbiting Message Relay satellite.
Nov. 14, 1986	Polar Bear	Scout	Experiments to study radio interference caused by Aurora Borealis, for DoD.

U.S.-Launched Space Probes 1975-1986

Date	Name	Launch Vehicle	Remarks
Aug. 20, 1975	Viking 1	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Chryse, Sept. 6, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere.
Sept. 9, 1975	Viking 2	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Utopia, July 20, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of the atmosphere.
Jan. 15, 1976	Helios 2	Titan IIIE-Centaur	Flew in highly elliptical orbit to within 41 million km of Sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had same West German and U.S. experiments as Helios 1 plus cosmic-ray burst detector.
Aug. 20, 1977	Voyager 2	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Swung around Jupiter in July 1979, arrived Saturn in 1981, going on to Uranus by 1986, Neptune by 1989.
Sep. 5, 1977	Voyager 1	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Passing Voyager 2 on the way, swung around Jupiter in Mar. 1979, arrived at Saturn in Nov. 1980, headed for outer solar system.
May 20, 1978	Pioneer Venus 1	Atlas-Centaur	Venus orbiter; achieved Venus orbit Dec. 4, returning imagery and data.
Aug. 8, 1978	Pioneer Venus 2	Atlas-Centaur	Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere Dec. 9, returned data.
None in 1984			
None in 1985			
None in 1986			

U.S. and Soviet Manned Spaceflights 1961-1986

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Vostok 1	Apr. 12, 1961	Yuriy A. Gagarin	0 : 1 : 48	First manned flight.
Mercury- Redstone 3	May 5, 1961	Alan B. Shepard, Jr.	0 : 0 : 15	First U.S. flight; suborbital.
Mercury- Redstone 4	July 21, 1961	Virgil I. Grissom	0 : 0 : 16	Suborbital; capsule sank after landing; astronaut safe.
Vostok 2	Aug. 6, 1961	German S. Titov	1 : 1 : 18	First flight exceeding 24 h.
Mercury-Atlas 6	Feb. 20, 1962	John H. Glenn, Jr.	0 : 4 : 55	First American to orbit.
Mercury-Atlas 7	May 24, 1962	M. Scott Carpenter	0 : 4 : 56	Landed 400 km beyond target.
Vostok 3	Aug. 11, 1962	Andriyan G. Nikolayev	3 : 22 : 25	First dual mission (with Vostok 4).
Vostok 4	Aug. 12, 1962	Pavel R. Popovich	2 : 22 : 59	Came within 6 km of Vostok 3.
Mercury-Atlas 8	Oct. 3, 1962	Walter M. Schirra, Jr.	0 : 9 : 13	Landed 8 km from target.
Mercury-Atlas 9	May 15, 1963	L. Gordon Cooper, Jr.	1 : 10 : 20	First U.S. flight exceeding 24 h.
Vostok 5	June 14, 1963	Valeriy F. Bykovskiy	4 : 23 : 6	Second dual mission (with Vostok 6).
Vostok 6	June 16, 1963	Valentina V. Tereshkova	2 : 22 : 50	First woman in space; within 5 km of Vostok 5.
Voskhod 1	Oct. 12, 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	1 : 0 : 17	First 3-man crew.
Voskhod 2	Mar. 18, 1965	Pavel I. Belyayev Aleksey A. Leonov	1 : 2 : 2	First extravehicular activity (Leonov, 10 min).
Gemini 3	Mar. 23, 1965	Virgil I. Grissom John W. Young	0 : 4 : 53	First U.S. 2-man flight; first manual maneuvers in orbit.
Gemini 4	June 3, 1965	James A. McDivitt Edward H. White II	4 : 1 : 56	21-min extravehicular activity (White).
Gemini 5	Aug. 21, 1965	L. Gordon Cooper, Jr.	7 : 22 : 55	Longest-duration manned flight to date.
Gemini 7	Dec. 4, 1965	Frank Borman James A. Lovell, Jr.	13 : 18 : 35	Longest-duration manned flight to date.
Gemini 6-A	Dec. 15, 1965	Walter M. Schirra, Jr. Thomas P. Stafford	1 : 1 : 51	Rendezvous within 30 cm of Gemini 7.
Gemini 8	Mar. 16, 1966	Neil A. Armstrong David R. Scott	0 : 10 : 41	First docking of 2 orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	June 3, 1966	Thomas P. Stafford Eugene A. Cernan	3 : 0 : 21	Extravehicular activity; rendezvous.
Gemini 10	July 18, 1966	John W. Young Michael Collins	2 : 22 : 47	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	Sept. 12, 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	2 : 23 : 17	First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km).
Gemini 12	Nov. 11, 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	3 : 22 : 35	Longest extravehicular activity to date (Aldrin, 5 hrs 37 min).
Soyuz 1	Apr. 23, 1967	Vladimir M. Komarov	1 : 2 : 37	Cosmonaut killed in reentry accident.
Apollo 7	Oct. 11, 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	10 : 20 : 9	First U.S. 3-man mission.
Soyuz 3	Oct. 26, 1968	Georgiy T. Beregovoy	3 : 22 : 51	Maneuvered near unmanned Soyuz 2.
Apollo 8	Dec. 21, 1968	Frank Borman James A. Lovell, Jr. William A. Anders	6 : 3 : 1	First manned orbit(s) of moon; first manned departure from Earth's sphere of influence; highest speed attained in manned flight to date.
Soyuz 4	Jan. 14, 1969	Vladimir A. Shatalov	2 : 23 : 23	Soyuz 4 and 5 docked and transferred 2 cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	Jan. 15, 1969	Boris V. Volynov Aleksey A. Yeliseyev Yevgeniy V. Khrunov	3 : 0 : 56	
Apollo 9	Mar. 3, 1969	James A. McDivitt David R. Scott Russell L. Schweickart	10 : 1 : 1	Successfully simulated in Earth orbit operation of lunar module to landing and takeoff from lunar surface and rejoining with command module.
Apollo 10	May 18, 1969	Thomas P. Stafford John W. Young Eugene A. Cernan	8 : 0 : 3	Successfully demonstrated complete system including lunar module descent to 14,300 m from the lunar surface.

U.S. and Soviet Manned Spaceflights 1961–1986

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Apollo 11	July 16, 1969	Neil A. Armstrong Michael Collins Edwin E. Aldrin, Jr.	8 : 3 : 9	First manned landing on lunar surface and safe return to Earth. First return of rock and soil samples to Earth, and manned deployment of experiments on lunar surface.
Soyuz 6	Oct. 11, 1969	Georgiy Shonin Valeriy N. Kubasov	4 : 22 : 42	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and Earth and celestial observation.
Soyuz 7	Oct. 12, 1969	Anatoliy V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	4 : 22 : 41	
Soyuz 8	Oct. 13, 1969	Vladimir A. Shatalov Aleksey S. Yeliseyev	4 : 22 : 50	
Apollo 12	Nov. 14, 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	10 : 4 : 36	Second manned lunar landing. Explored surface of moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on Apr. 19, 1967.
Apollo 13	Apr. 11, 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	5 : 22 : 55	Mission aborted; explosion in service module. Ship circled moon, with crew using LM as "lifeboat" until just before reentry.
Soyuz 9	June 1, 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17 : 16 : 59	Longest manned spaceflight to date.
Apollo 14	Jan. 31, 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	9 : 0 : 2	Third manned lunar landing. Mission demonstrated pinpoint landing capability and continued manned exploration.
Soyuz 10	Apr. 22, 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev	1 : 23 : 46	Docked with Salyut 1, but crew did not board space station launched 19 Apr. Crew recovered Apr. 24, 1971.
Soyuz 11	June 6, 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	23 : 18 : 22	Docked with Salyut 1 and Soyuz 11 crew occupied space station for 22 days. Crew perished during final phase of Soyuz 11 capsule recovery on June 30, 1971.
Apollo 15	July 26, 1971	David R. Scott Alfred M. Worden James B. Irwin	12 : 7 : 12	Fourth manned lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's inflight EVA of 38 min 12 sec was performed during return trip.
Apollo 16	Apr. 16, 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II	11 : 1 : 51	Fifth manned lunar landing, with Lunar Roving Vehicle.
Apollo 17	Dec. 7, 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	12 : 13 : 52	Sixth and final Apollo manned lunar landing, again with roving vehicle.
Skylab 2	May 25, 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	28 : 0 : 50	Docked with Skylab 1 (launched unmanned May 14) for 28 days. Repaired damaged station.
Skylab 3	July 28, 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	59 : 11 : 9	Docked with Skylab 1 for more than 59 days.
Soyuz 12	Sept. 27, 1973	Vasiliy G. Lazarev Oleg G. Makarov	1 : 23 : 16	Checkout of improved Soyuz.
Skylab 4	Nov. 16, 1973	Gerald P. Carr Edward G. Gibson William R. Pogue	84 : 1 : 16	Docked with Skylab 1 in long-duration mission; last of Skylab program.
Soyuz 13	Dec. 18, 1973	Petr I. Klimuk Valentin V. Lebedev	7 : 20 : 55	Astrophysical, biological, and earth resources experiments.
Soyuz 14	July 3, 1974	Pavel R. Popovich Yuriy P. Artyukhin	15 : 17 : 30	Docked with Salyut 3 and Soyuz 14 crew occupied space station.
Soyuz 15	Aug. 26, 1974	Gennadiy V. Sarafanov Lev S. Demin	2 : 0 : 12	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	Dec. 2, 1974	Anatoliy V. Filipchenko Nikolay N. Rukavishnikov	5 : 22 : 24	Test of ASTP configuration.

U.S. and Soviet Manned Spaceflights 1961–1986

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz 17	Jan. 10, 1975	Aleksay A. Gubarev Georgiy M. Grechko	29 : 13 : 20	Docked with Salyut 4 and occupied station.
Anomaly	Apr. 5, 1975	Vasiliy G. Lazarev Oleg G. Makarov	0 : 0 : 20	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	May 24, 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	62 : 23 : 20	Docked with Salyut 4 and occupied station.
Soyuz 19	July 15, 1975	Aleksey A. Leonov Valeriy N. Kubasov	5 : 22 : 31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo (ASTP)	July 15, 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	9 : 1 : 28	Docked with Soyuz 19 in joint experiments of ASTP mission.
Soyuz 21	July 6, 1976	Boris V. Volynov Vitaliy M. Zholobov	48 : 1 : 32	Docked with Salyut 5 and occupied station.
Soyuz 22	Sept. 15, 1976	Valeriy F. Bykovskiy Vladimir V. Aksenov	7 : 21 : 54	Earth resources study with multispectral camera system.
Soyuz 23	Oct. 14, 1976	Vyacheslav D. Zudov Valeriy I. Rozhdestvenskiy	2 : 0 : 6	Failed to dock with Salyut 5.
Soyuz 24	Feb. 7, 1977	Viktor V. Gorbatko Yuriy N. Glazkov	17 : 17 : 23	Docked with Salyut 5 and occupied station.
Soyuz 25	Oct. 9, 1977	Vladimir V. Kovalenok Valeriy V. Ryumin	2 : 0 : 46	Failed to achieve hard dock with Salyut 6 station.
Soyuz 26	Dec. 10, 1977	Yuriy V. Romanenko Georgiy M. Grechko	37 : 10 : 6	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 days 10 hrs.
Soyuz 27	Jan. 10, 1978	Vladimir A. Dzhanibekov Oleg G. Makarov	64 : 22 : 53	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 5 days 22 hrs 59 min.
Soyuz 28	Mar. 2, 1978	Aleksey A. Gubarev Vladimir Remek	7 : 22 : 17	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	June 15, 1978	Vladimir V. Kovalenok Aleksandr S. Ivanchenkov	79 : 15 : 23	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 139 days 14 hrs 48 min.
Soyuz 30	June 27, 1978	Petr I. Klimuk Miroslaw Hermaszewski	7 : 22 : 4	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	Aug. 26, 1978	Valeriy F. Bykovskiy Sigmund Jaehn	67 : 20 : 14	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 7 days 20 hrs 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	Feb. 25, 1979	Vladimir A. Lyakhov Valeriy V. Ryumin	108 : 4 : 24	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 175 days 36 min.
Soyuz 33	Apr. 10, 1979	Nikolay N. Rukavishnikov Georgi I. Ivanov	1 : 23 : 1	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	June 6, 1979	(unmanned at launch)	73 : 18 : 17	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned unmanned.
Soyuz 35	Apr. 9, 1980	Leonid I. Popov Valeriy V. Ryumin	55 : 1 : 29	Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration, 184 days 20 hrs 12 min.
Soyuz 36	May 26, 1980	Valeriy N. Kubasov Bertalan Farkas	65 : 20 : 54	Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 7 days 20 hrs 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	June 5, 1980	Yuriy V. Malyshev Vladimir V. Aksenov	3 : 22 : 21	Docked with Salyut 6. First manned flight of new-generation ferry.
Soyuz 37	July 23, 1980	Viktor V. Gorbatko Pham Tuan	79 : 15 : 17	Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 7 days 20 hrs 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	Sept. 18, 1980	Yuriy V. Romanenko Arnaldo Tamayo Mendez	7 : 20 : 43	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	Nov. 27, 1980	Leonid D. Kizim Oleg G. Makarov Gennadiy M. Strekalov	12 : 19 : 8	Docked with Salyut 6. First 3-man flight in Soviet program since 1971.

U.S. and Soviet Manned Spaceflights 1961–1986

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Soyuz T-4	Mar. 12, 1981	Vladimir V. Kovalenok Viktor P. Savinykh	74 : 18 : 38	Docked with Salyut 6.
Soyuz 39	Mar. 22, 1981	Vladimir A. Dzhanibekov Jugderdemidiyn Gurragcha	7 : 20 : 43	Docked with Salyut 6. Gurragcha first Mongolian cosmonaut to orbit.
Space Shuttle Columbia (STS 1)	Apr. 12, 1981	John W. Young Robert L. Crippen	2 : 6 : 21	First flight of Space Shuttle, tested spacecraft in orbit. First landing of airplanelike craft from orbit for reuse.
Soyuz 40	May 14, 1981	Leonid I. Popov Dumitru Prunariu	7 : 20 : 41	Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit.
Space Shuttle Columbia (STS 2)	Nov. 12, 1981	Joe H. Engle Richard H. Truly	2 : 6 : 13	Second flight of Space Shuttle, first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.
Space Shuttle Columbia (STS 3)	Mar. 22, 1982	Jack R. Lousma C. Gordon Fullerton	8 : 4 : 49	Third flight of Space Shuttle, second scientific payload (OSS 1). Second test of remote manipulator arm. Flight extended 1 day because of flooding at primary landing site; alternate landing site used. Returned for reuse.
Soyuz T-5	May 13, 1982	Anatoliy Berezhovoy Valentin Lebedev	211 : 9 : 5	Docked with Salyut 7. Crew duration of 211 days. Crew returned in Soyuz T-7.
Soyuz T-6	June 24, 1982	Vladimir Dzhanibekov Aleksandr Ivanchenkov Jean-Loup Chretien	7 : 21 : 51	Docked with Salyut 7. Chretien first French cosmonaut to orbit.
Space Shuttle Columbia (STS 4)	June 27, 1982	Thomas K. Mattingly II Henry W. Hartsfield, Jr.	7 : 1 : 9	Fourth flight of Space Shuttle, first DoD payload, additional scientific payloads. Returned July 4. Completed orbital flight testing program. Returned for reuse.
Soyuz T-7	Aug. 19, 1982	Leonid Popov Aleksandr Serebrov Svetlana Savitskaya	7 : 21 : 52	Docked with Salyut 7. Savitskaya second Soviet woman to orbit. Crew returned in Soyuz T-5.
Space Shuttle Columbia (STS 5)	Nov. 11, 1982	Vance D. Brand Robert F. Overmyer Joseph P. Allen William B. Lenoir	5 : 2 : 14	Fifth flight of Space Shuttle, first operational flight; launched 2 commercial satellites (SBS 3 and Anik C-3); first flight with 4 crew-members. EVA test canceled when spacesuits malfunctioned.
Space Shuttle Challenger (STS 6)	Apr. 4, 1983	Paul J. Weitz Karol J. Bobko Donald H. Peterson Story Musgrave	5 : 0 : 24	Sixth flight of Space Shuttle, launched TDRS 1.
Soyuz T-8	Apr. 20, 1983	Vladimir Titov Gennady Strekalov Aleksander Serebrov	2 : 0 : 18	Failed to achieve docking with Salyut 7 station.
Space Shuttle Challenger (STS 7)	June 18, 1983	Robert L. Crippen Frederick H. Hauck John M. Fabian Sally K. Ride Norman T. Thagard	6 : 2 : 24	Seventh flight of Space Shuttle, launched 2 commercial satellites (Anik C-2 and Palapa B-1), also launched and retrieved SPAS 01; first flight with 5 crewmembers, including first woman U.S. astronaut.
Soyuz T-9	June 28, 1983	Vladimir Lyakhov Aleksandr Aleksandrov	149 : 9 : 46	Docked with Salyut 7 station.
Space Shuttle Challenger (STS 8)	Aug. 30, 1983	Richard H. Truly Daniel C. Brandenstein Dale A. Gardner Guion S. Bluford, Jr. William E. Thornton	6 : 1 : 9	Eighth Flight of Space Shuttle, launched one commercial satellite (Insat 1-B), first flight of U.S. black astronaut.
Space Shuttle Columbia (STS 9)	Nov. 28, 1983	John W. Young Brewster W. Shaw Owen K. Garriott Robert A. R. Parker Byron K. Lichtenberg Ulf Merbold	10 : 7 : 47	Ninth flight of Space Shuttle, first flight of Spacelab 1, first flight of 6 crewmembers, one of whom was West German, first non-U.S. astronaut to fly in U.S. space program.

U.S. and Soviet Manned Spaceflights 1961–1986

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Challenger (STS-41B)	Feb. 3, 1984	Vance D. Brand Robert L. Gibson Bruce McCandless Ronald E. McNair Robert L. Stewart	7 : 23 : 16	Tenth flight of Space Shuttle, two communication satellites failed to achieve orbit. First use of Manned Maneuvering Unit (MMU) in space.
Soyuz T-10	Feb. 8, 1984	Leonid Kizim Vladimir Solovev Oleg Atkov	62 : 22 : 43	Docked with Salyut 7 station. Crew set space duration record of 237 days. Crew returned in Soyuz T-11.
Soyuz T-11	Apr. 3, 1984	Yuriy Malyshev Gennadiy Strekalov Rakesh Sharma	181 : 21 : 48	Docked with Salyut 7 station. Sharma first Indian in space. Crew returned in Soyuz T-10.
Space Shuttle Challenger (STS-41C)	Apr. 6, 1984	Robert L. Crippen Frances R. Scobee Terry J. Hart George D. Nelson James D. Van Hoften	6 : 23 : 41	Eleventh flight of Space Shuttle, deployment of LDEF-1, for later retrieval, Solar Maximum Satellite retrieved, repaired, and redeployed.
Soyuz T-12	July 17, 1984	Vladimir Dzhanibekov Svetlana Savitskaya Igor Volk	11 : 19 : 14	Docked with Salyut 7 station. First woman extravehicular activity.
Space Shuttle Discovery (STS-41D)	Aug. 30, 1984	Henry W. Hartsfield Michael L. Coats Richard M. Mullane Steven A. Hawley Judith A. Resnick Charles D. Walker	6 : : 56	Twelfth flight of Space Shuttle. First flight of U.S. non-astronaut.
Space Shuttle Challenger (STS-41G)	Sept. 5, 1984	Robert L. Crippen Jon A. McBride Kathryn D. Sullivan Sally K. Ride David Leestma Paul D. Scully-Power Marc Garneau	8 : 5 : 24	Thirteenth flight of Space Shuttle, first flight of 7 crewmembers, including first flight of two U.S. women and one Canadian.
Space Shuttle Discovery (STS-51A)	Nov. 8, 1984	Frederick H. Hauck David M. Walker Joseph P. Allen Anna L. Fisher Dale A. Gardner	7 : 23 : 45	Fourteenth flight of Space Shuttle, first retrieval and return of two disabled communications satellites (Westar 6, Palapa B2) to Earth.
Space Shuttle Discovery (STS-51C)	Jan. 24, 1985	Thomas K. Mattingly Loren J. Shriver Ellison S. Onizuka James F. Buchli Gary E. Payton	3 : 1 : 33	Fifteenth STS flight. Dedicated DoD mission.
Space Shuttle Discovery (STS-51D)	Apr. 12, 1985	Karol J. Bobko Donald E. Williams M. Rhea Seddon S. David Griggs Jeffrey A. Hoffman Charles D. Walker E.J. "Jake" Garn	6 : 23 : 55	Sixteenth STS flight. Two communications satellites. First U.S. Senator in space.
Space Shuttle Challenger (STS-51B)	Apr. 29, 1985	Robert F. Overmyer Frederick D. Gregory Don L. Lind Norman E. Thagard William E. Thornton Lodewijk Vandenberg Taylor Wang	7 : : 9	Seventeenth STS flight. Spacelab-3 in cargo bay of shuttle.
Soyuz T-13	June 5, 1985	Vladimir Dzhanibekov Viktor Savinykh	112 : 3 : 12	Repair of Salyut-7. Dzhanibekov returned to earth with Grechko on Soyuz T-13 spacecraft, Sept. 26, 1985.

U.S. and Soviet Manned Spaceflights 1961–1986

Spacecraft	Launch Date	Crew	Flight Time (days:hrs:min)	Highlights
Space Shuttle Discovery (STS-51G)	June 17, 1985	Daniel C. Brandenstein John O. Creighton Shannon W. Lucid John M. Fabian Steven R. Nagel Patrick Baudry Sultan bin Salman bin Abdul-Aziz Al-Saud	7 : 1 : 39	Eighteenth STS flight. Three communications satellites. One reusable payload-Spartan-1. First U.S. flight with French and Saudi Arabian crewmen.
Space Shuttle Challenger (STS-51F)	July 29, 1985	Charles G. Fullerton Roy D. Bridges Karl C. Henize Anthony W. England F. Story Musgrave Loren W. Acton John-David F. Bartoe	7 : 22 : 45	Nineteenth STS flight. Spacelab-2 in cargo bay.
Space Shuttle Discovery (STS-51I)	Aug. 27, 1985	Joe H. Engle Richard O. Covey James D. van Hoften William F. Fisher John M. Lounge	7 : 2 : 18	Twentieth STS flight. Launched three communications satellites. Repaired Syncom IV-3.
Soyuz T-14	Sep. 17, 1985	Vladimir Vasyutin Georgiy Grechko Aleksandr Volkov	64 : 21 : 52	Docked with Salyut-7 station. Viktor Savinykh, Aleksandr Volkov and Vladimir Vasyutin returned to Earth Nov. 21, 1985 when Vasyutin became ill.
Space Shuttle Atlantis (STS-51J)	Oct. 3, 1985	Karol J. Bobko Ronald J. Grabe Robert A. Stewart David C. Hilmers William A. Pailles	4 : 1 : 45	Twenty-first STS flight. Dedicated DoD mission.
Space Shuttle Challenger (STS-61A)	Oct. 30, 1985	Henry W. Hartsfield Steven R. Nagel Bonnie J. Dunbar James F. Buchli Guion S. Bluford Ernst Messerschmid Reinhard Furrer Wubbo J. Ockels	7 : : 45	Twenty-second STS flight. Dedicated German Spacelab D-1 in shuttle cargo bay.
Space Shuttle Atlantis (STS-61B)	Nov. 27, 1985	Brewster H. Shaw Bryan D. O'Connor Mary L. Cleve Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker	6 : 22 : 54	Twenty-third STS flight. Launched three communications satellites. First flight of Mexican astronaut.
Space Shuttle Columbia (STS-61C)	Jan. 12, 1986	Robert L. Gibson Charles F. Bolden, Jr. Franklin Chang-Diaz Steven A. Hawley George D. Nelson Roger Cenker Cong. Bill Nelson	6 : 2 : 4	Twenty-fourth STS flight. Launched one communications satellite. First member of U.S. House of Representatives in space.
Soyuz T-15	Mar. 13, 1986	Leonid Kizim Vladimir Solovyov	125 : 1 : 1	Docked with MIR space station on May 5/6 transferred to Salyut 7 complex. On June 25/26 transferred from Salyut 7 back to MIR.

U.S. Space Launch Vehicles

Vehicle	Stages	Propellant ^a	Thrust (kilo- newtons)	Max. Dia. × Height (m)	Max. Payload (kg) ^b			First Launch ^c	
					185-Km Orbit	Geosynch- Transfer Orbit	Circular Sun- Synch. Orbit		
Scout	1. Algol IIIA.....	Solid.....	431.1	1.14 × 22.9	255 205 ^d	—	155 ^d	1979(60)	
	2. Castor IIA.....	Solid.....	285.2						
	3. Antares IIIA.....	Solid.....	83.1						
	4. Altair IIIA.....	Solid.....	25.6						
Delta 2900 Series (Thor-Delta)	1. Thor plus.....	LOX/RP-1.....	912.0	2.44 × 35.4	2,000 1,410 ^d	705	1,250 ^d	1973(60)	
	9 TX 354-5.....	Solid.....	147 each						
	2. Delta.....	N ₂ O ₄ /Aerozine-50 ..	44.2						
Delta 3900 Series (Thor-Delta) ^e	3. TE 364-4.....	Solid.....	65.8	2.44 × 35.4	3,045 2,180 ^d	1,275	2,135 ^d	1982(60)	
	1. Thor plus.....	LOX/RP-1.....	912.0						
	9 TX 526-2.....	Solid.....	375 each						
Atlas E	2. Delta.....	N ₂ O ₄ /Aerozine-50 ..	44.2	3.05 × 28.1	2,090 ^{df}	—	1,500 ^d	1972(67)	
	1. Atlas booster & sustainer.....	LOX/RP-1.....	1,722.0						
Atlas-Centaur	1. Atlas booster & sustainer.....	LOX/RP-1.....	1,913.0	3.05 × 45.0	6,100	2,360	—	1984(62)	
	2. Centaur.....	LOX/LH ₂	146.0						
Titan IIB-Agena	1. LR-87.....	N ₂ O ₄ /Aerozine.....	2,341.0	3.05 × 48.4	3,600 ^d	—	3,060 ^d	1966	
	2. LR-91.....	N ₂ O ₄ /Aerozine.....	455.1						
	3. Agena.....	IRFNA/UDMH.....	71.2						
Titan III(34)D/ IUS	1. Two 5½-segment, 3.05 m dia.....	Solid.....	11,564.8	3.05 × 48.0	14,920	1,850 ^d	—	1982	
	2. LR-87.....	N ₂ O ₄ /Aerozine.....	2,366.3						
	3. LR-91.....	N ₂ O ₄ /Aerozine.....	449.3						
	4. IUS 1st stage.....	Solid.....	275.8						
	5. IUS 2nd stage.....	Solid.....	115.7						
Titan III(34)D/ Transtage	Same as Titan III(34)D plus: 4. Transtage.....	N ₂ O ₄ /Aerozine.....	69.8	3.05 × 46.9	14,920	1,855 ^d	—	1984 ^h	
Space Shuttle (reusable)	1. Orbiter; 3 main engines (SSMEs) fire in parallel with SRBs.....				LOX/LH ₂	1,670 each	23.79 × 37.24 wing long span	29,500 in full performance configuration	1981
	2. Two-solid-fueled rocket boosters (SRBs) fire in parallel with SSMEs.....				AL/NH ₄ CLO ₄ / PBAN.....	11,790 each	3.71 × 45.45		
	Mounted on ex- ternal tank (ET).....						8.40 × 46.88		

^a Propellant abbreviations used are as follows: liquid oxygen and a modified kerosene = LOX/RP/RJ; solid propellant combining in a single mixture both fuel and oxidizer = Solid; inhibited red-fuming nitric acid and unsymmetrical dimethylhydrazine = IRFNA/UDMH; nitrogen tetroxide and UDMH/N₂H₄ = N₂O₄/aerozine; liquid oxygen and liquid hydrogen = LOX/LH₂; aluminum, ammonium perchlorate, and polybutadiene acrolonitrile terpolymer = AL/NH₄CLO₄/PBAN.

^b Due east launch except as indicated.

^c The date of first launch applies to this latest modification with a date in parentheses for the initial version.

^d Polar launch.

^e Maximum performance based on 3920, 3920/PAM configurations. PAM = payload assist module (a private venture).

^f With dual TE 364-4.

^g With 96° flight azimuth.

^h Initial operational capability in December 1982; launch to be scheduled as needed.

NOTE: Data should not be used for detailed NASA mission planning without concurrence of the director of Space Transportation System Support Programs.

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY—BUDGET AUTHORITY
(in millions of dollars)

Fiscal Year	NASA		Defense	Energy	Com- merce	Interior	Agricul- ture	NSF	Total Space
	Total	Space ^a							
1959.....	330.9	260.9	489.5	34.3	...	...	...	...	784.7
1960.....	523.6	461.5	560.9	43.3	...	...	...	0.1	1,065.8
1961.....	964.0	926.0	813.9	67.7	...	...	...	.6	1,808.2
1962.....	1,824.9	1,796.8	1,298.2	147.8	50.7	...	...	1.3	3,294.8
1963.....	3,673.0	3,626.0	1,549.9	213.9	43.2	...	...	1.5	5,434.5
1964.....	5,099.7	5,016.3	1,599.3	210.0	2.8	...	...	3.0	6,831.4
1965.....	5,249.7	5,137.6	1,573.9	228.6	12.2	...	...	3.2	6,955.5
1966.....	5,174.9	5,064.5	1,688.8	186.8	26.5	...	...	3.2	6,969.8
1967.....	4,965.6	4,830.2	1,663.6	183.6	29.3	...	...	2.8	6,709.5
1968.....	4,587.3	4,430.0	1,921.8	145.1	28.1	0.2	0.5	3.2	6,528.9
1969.....	3,990.9	3,822.0	2,013.0	118.0	20.0	.2	.7	1.9	5,975.8
1970.....	3,745.8	3,547.0	1,678.4	102.8	8.0	1.1	.8	2.4	5,340.5
1971.....	3,311.2	3,101.3	1,512.3	94.8	27.4	1.9	.8	2.4	4,740.9
1972.....	3,306.6	3,071.0	1,407.0	55.2	31.3	5.8	1.6	2.8	4,574.7
1973.....	3,406.2	3,093.2	1,623.0	54.2	39.7	10.3	1.9	2.6	4,824.9
1974.....	3,036.9	2,758.5	1,766.0	41.7	60.2	9.0	3.1	1.8	4,640.3
1975.....	3,229.1	2,915.3	1,892.4	29.6	64.4	8.3	2.3	2.0	4,914.3
1976.....	3,550.3	3,225.4	1,983.3	23.3	71.5	10.4	3.6	2.4	5,319.9
Transitional Quarter	931.8	849.2	460.4	4.6	22.2	2.6	.9	.6	1,340.5
1977.....	3,817.8	3,440.2	2,411.9	21.7	90.8	9.5	6.3	2.4	5,982.8
1978.....	4,060.1	3,622.9	2,738.3	34.4	102.8	9.7	7.7	2.4	6,518.2
1979.....	4,595.5	4,030.4	3,035.6	58.6	98.4	9.9	8.2	2.4	7,243.5
1980.....	5,240.2	4,680.4	3,848.4	39.6	92.6	11.7	13.7	2.4	8,688.8
1981.....	5,518.4	4,992.4	4,827.7	40.5	87.0	12.3	15.5	2.4	9,977.8
1982.....	6,043.9 ^b	5,527.6	6,678.7	60.6	144.5	12.1	15.2	2.0	12,440.7
1983.....	6,875.3 ^c	6,327.9	9,018.9	38.9	177.8	4.6	20.4	0.0 ^d	15,588.5
1984.....	7,248.0	6,648.3	10,194.9	34.1	236.0	3.0	19.4	0.0	17,135.7
1985.....	7,572.6	6,924.9	12,767.9	34.0	422.9	2.0	14.8	0.0	20,166.5
1986.....	7,766.0	7,165.0	14,126.0	34.6	308.9	2.0	22.9	0.0	21,659.4
1987 [est.].....	10,507.0	9,809.0	15,717.0	47.0	277.4	2.0	24.0	0.0	25,876.4
1988 [est.].....	9,481.0	8,756.0	17,196.0	90.3	340.1	2.0	24.8	0.0	26,409.2

^aExcludes amounts for air transportation (subfunction 402).

^bIncludes \$33.5 million unobligated funds that lapsed.

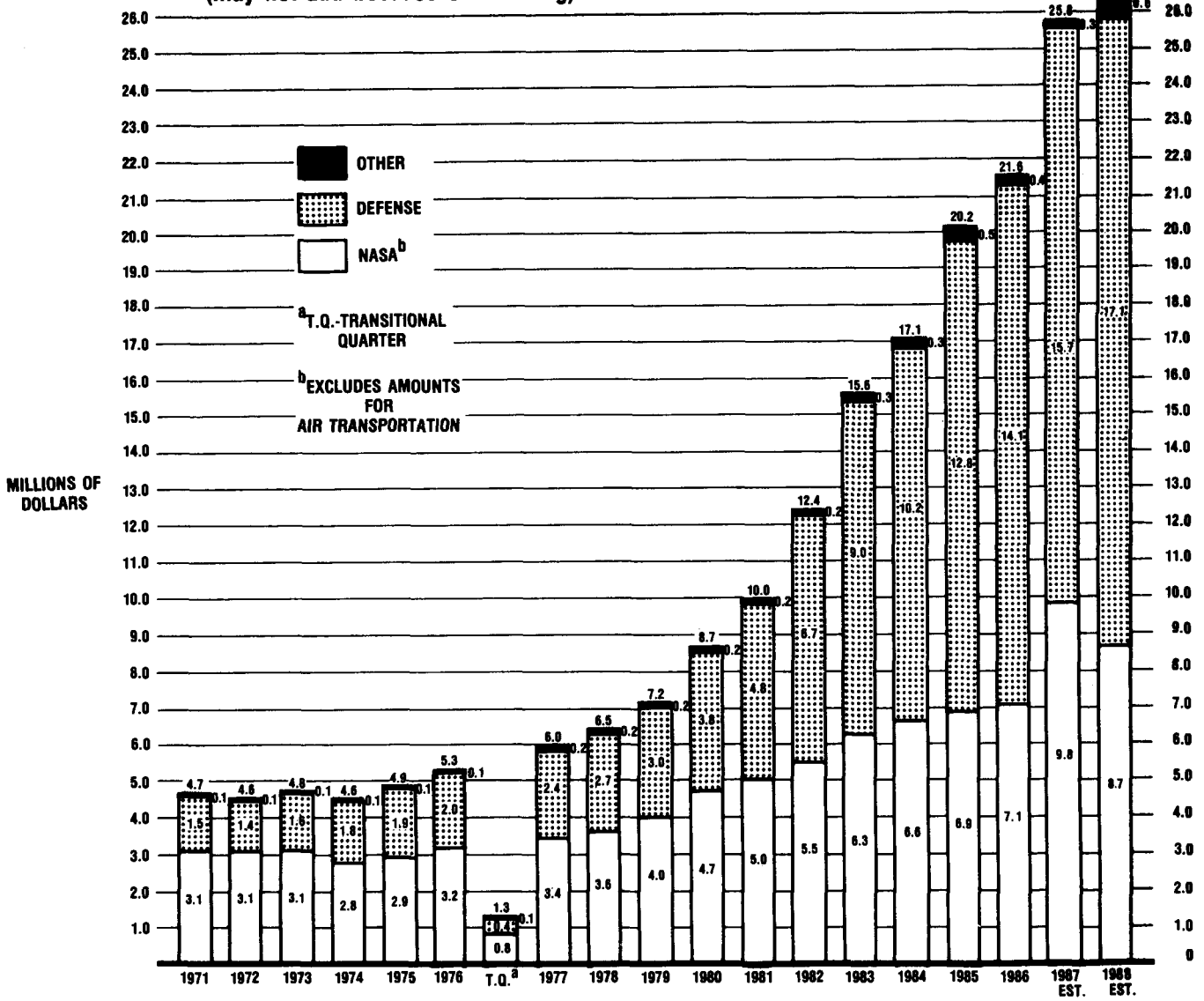
^cIncludes \$37.6 million for reappropriation of prior year funds.

^dNSF funding of balloon research transferred to NASA.

SOURCE: Office of Management and Budget.

U.S. Space Budget—Budget Authority FY 1971-1986

(may not add because of rounding)



SOURCE: OFFICE OF MANAGEMENT AND BUDGET

APPENDIX E-2

Space Activities Budget

(in millions of dollars by fiscal year)

Federal Space Programs	Budget Authority			Budget Outlays		
	1986 Actual	1987 Estimate	1988 Estimate	1986 Actual	1987 Estimate	1988 Estimate
Federal agencies:						
NASA ^a	7,165.0	9,809.0	8,756.0	6,756.0	7,254.0	8,851.0
Defense	14,126.0	15,717.0	17,196.0	11,448.5	14,252.2	15,395.8
Energy	34.6	47.0	90.3	34.7	47.3	90.3
Commerce	308.9	277.4	340.1	316.9	299.2	316.1
Interior	2.0	2.0	2.0	2.0	2.0	2.0
NSF ^b	0.0	0.0	0.0	0.0	0.0	0.0
Agriculture	22.9	24.0	24.8	22.9	24.0	24.8
Total	21,659.4	25,876.4	26,409.2	18,581.0	21,878.7	24,680.0

^aExcludes amounts for air transportation. Includes \$37.6 million for reappropriation of prior year funds.

SOURCE: Office of Management and Budget.

^bNSF funding for balloon research transferred to NASA.

APPENDIX E-3

Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Aeronautics Programs	Budget Authority			Budget Outlays		
	1986 Actual	1987 Estimate	1988 Estimate	1986 Actual	1987 Estimate	1988 Estimate
NASA ^a	601.0	698.0	725.0	648.0	622.0	683.0
Department of Defense ^b	4,927.0	5,173.0	7,009.0	4,372.6	4,866.9	5,923.0
Department of Transportation ^c	1,132.1	946.3	1,500.0	1,050.3	1,037.2	1,100.6
Total	6,660.1	6,817.3	9,234.0	6,070.9	6,526.1	7,706.6

^aResearch and Development, Construction of Facilities, Research and Program Management.

SOURCE: Office of Management and Budget.

^bResearch, Development, Testing, and Evaluation of aircraft and related equipment.

^cFederal Aviation Administration: Research, Engineering, and Development; Facilities, Engineering, and Development.

Information: To obtain general information about the contents of this report, contact S.E. Kale, Code XH, NASA Headquarters, Washington, D.C. 20546, (202) 453-8300.

THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release

February 3, 1986

EXECUTIVE ORDER

PRESIDENTIAL COMMISSION ON THE
SPACE SHUTTLE CHALLENGER ACCIDENT

By the authority vested in me as President by the Constitution and statutes of the United States of America, including the Federal Advisory Committee Act, as amended (5 U.S.C. App. D), and in order to establish a commission of distinguished Americans to investigate the accident to the Space Shuttle Challenger, it is hereby ordered as follows:

Section 1. Establishment. (a) There is established the Presidential Commission on the Space Shuttle Challenger Accident. The Commission shall be composed of not more than 20 members appointed or designated by the President. The members shall be drawn from among distinguished leaders of the government, and the scientific, technical, and management communities.

(b) The President shall designate a Chairman and a Vice Chairman from among the members of the Commission.

Sec. 2. Functions. (a) The Commission shall investigate the accident to the Space Shuttle Challenger, which occurred on January 28, 1986.

(b) The Commission shall:

(1) Review the circumstances surrounding the accident to establish the probable cause or causes of the accident; and

(2) Develop recommendations for corrective or other action based upon the Commission's findings and determinations.

(c) The Commission shall submit its final report to the President and the Administrator of the National Aeronautics and Space Administration within one hundred and twenty days of the date of this order.

Sec. 3. Administration. (a) The heads of Executive departments and agencies shall, to the extent permitted by law, provide the Commission with such information as it may require for purposes of carrying out its functions.

(b) Members of the Commission shall serve without compensation for their work on the Commission. However, members appointed from among private citizens of the United States may be allowed travel expenses, including per diem in lieu of subsistence, to the extent permitted by law for persons serving intermittently in the government service (5 U.S.C. 5701-5707).

(c) To the extent permitted by law, and subject to the availability of appropriations, the Administrator of the National Aeronautics and Space Administration shall provide the Commission with such administrative services, funds, facilities, staff, and other support services as may be necessary for the performance of its functions.

Sec. 4. General Provisions. (a) Notwithstanding the provisions of any other Executive Order, the functions of the President under the Federal Advisory Committee Act which are applicable to the Commission, except that of reporting annually to the Congress, shall be performed by the Administrator of the National Aeronautics and Space Administration, in accordance with guidelines and procedures established by the Administrator of General Services.

(b) The Commission shall terminate 60 days after submitting its final report.

RONALD REAGAN

THE WHITE HOUSE,
February 3, 1986.

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Office of the Press Secretary

For Immediate Release

August 15, 1986

STATEMENT BY THE PRESIDENT

I am announcing today two steps that will ensure America's leadership in space exploration and utilization. First, the United States will, in FY 1987, start building a fourth Space shuttle to take the place of Challenger which was destroyed on January 28th. This decision will bring our shuttle fleet up to strength and enable the United States to safely and energetically project a manned presence in space.

Without the fourth orbiter, NASA's capabilities would be severely limited and long-term projects for the development of space would have to be either postponed, or even canceled. A fourth orbiter will enable our shuttles to accomplish the mission for which they were originally intended and permit the United States to move forward with new exciting endeavors like the building of a permanently manned space station.

My second announcement concerns the fundamental direction of the space program. NASA and our shuttles will continue to lead the way, breaking new ground, pioneering new technology, and pushing back the frontiers. It has been determined, however, that NASA will no longer be in the business of launching private satellites.

The private sector, with its ingenuity and cost effectiveness, will be playing an increasingly important role in the American space effort. Free enterprise corporations will become a highly competitive method of launching commercial satellites and doing those things which do not require a manned presence in space. These private firms are essential in clearing away the backlog that has built up during this time when our shuttles are being modified.

We must always set our sights on tomorrow. NASA and our shuttles can't be committing their scarce resources to things which can be done better and cheaper by the private sector. Instead, NASA and the four shuttles should be dedicated to payloads important to national security and foreign policy, and, even more, on exploration, pioneering, and developing new technologies and uses of space. NASA will keep America on the leading edge of change; the private sector will take over from there. Together, they will ensure that our country has a robust, balanced, and safe space program.

It has been over 6 months since the tragic loss of the Challenger and her gallant crew. We have done everything humanly possible to discover the organizational and technical causes of the disaster and to correct the situation. The greatest tribute we can pay to those brave pathfinders who gave their lives on the Challenger is to move forward and rededicate ourselves to America's leadership in space.